Prioritization of Rural Roads Maintenance in Hilly Terrain

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DOCTOR OF PHILOSOPHY

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ABSTRACT

Pavements are imperative assets of highways which need timely maintenance for efficient use of road maintenance fund. The deferred pavement maintenance strategies results in huge economic loss and badly affects the development of any country. The available fund for road maintenance is also limited. Hence, for worthy utilization of road maintenance funds, it is required to assess the condition of pavements which needs to be maintained first and are in utter worst condition. Rural Roads in Himachal Pradesh, India plays a vital role in the development of state. With an increasing pace of rural road construction of 1000 kms per year and introduction of PMGSY, the total rural road network contribution in the state is approximately 26000 kms with 62% of tarred roads. In order to preserve this important asset, along with the rapid construction pace of this huge rural road network, simultaneous maintenance is also required in a timely manner. Prioritization of pavements is required in order to assess the pavement conditions and providing maintenance to the deprived one. Various pavement indexes such as Pavement Condition Index (PCI), Roughness Index (RI), etc, have been used to assess the condition of pavements. An attempt has been made to develop Rural Road Maintenance Priority Index (RRMPI) for rural road network in Himachal Pradesh, India. Rural Road Maintenance Priority Index (RRMPI) is a function of overall functional condition index (OFCI) and overall structural condition index (OSCI). RRMPI is an index of scale 0-100, in which 0 signifies worst condition of pavement and 100 signifies best condition of pavement. The proposed index is expected to provide better reflection of pavement condition and helps in prioritizing maintenance strategies. In the present study, the developed RRMPI has been used to select maintenance strategy for the selected 12 rural road stretches in Himachal Pradesh. International Roughness Index (IRI) plays an important role in developing maintenance strategies for the pavements. IRI depends upon various distress parameters such as cracking, ravelling, potholes, rutting, patching etc. In the present study, attempts has been made to correlate International Roughness Index with various distress parameters so as to eliminate the cost incurred in determining IRI using expensive equipments. The Weightage has been given to each distress parameter based on a questionnaire survey using Analytical Hierarchy Process (AHP). The pavement distress data collected on selected twelve rural road stretches in the vicinity of Shimla and Solan districts of Himachal Pradesh is used to develop linear and non-linear regression model between IRI and distress parameters. Artificial Neural Network (ANN) is also used to develop the IRI model. All developed models have been studied, compared and it is found that non-linear

regression model with a R^2 value of 0.84 and MSE of 0.16 is considered as best model for predicting International Roughness Index as compared to other models.

Structural Evaluation of pavements is essential to assess the structural strength of different layers of pavement. It also helps in determining the remaining life of a pavement and the thickness of overlay required. Surface Deflection is the structural response that is easy to measure and hence, commonly used parameter in structural evaluation. In the present study, an attempt has been made to develop a relationship between surface deflection and various structural parameters of pavements selected on low volume flexible rural roads in Himachal Pradesh. Benkelman Beam has been used to determine characteristic deflection on selected 12 rural road stretches in Shimla and Solan district of Himachal Pradesh. Because the conduction of Benkelman Beam Deflection (BBD) test is costly and difficult to carry out in the region of Himachal Pradesh due to hilly and narrow rural roads leading to disruption of traffic, hence, models have been developed to predict surface deflection value using Soaked CBR, Un-soaked CBR, Average Annual Daily Traffic (AADT) and Age of pavement from last overlay (in years). Another model has also been developed to estimate surface deflection using K-value, AADT and age of pavement. Multiple models have been developed using linear regression model. The various developed models have been studied, compared and best model is suggested supporting better coefficient of determination value and root mean square error (RMSE).

Keywords: *Pavement distresses, roughness index, functional evaluation, structural evaluation, prioritization index*

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CHAPTER 1

INTRODUCTION

1.1 General

A pavement is a load-carrying layered structure constructed on a firm supporting natural soil called sub-grade. The main functions of a pavement includes: Providing a firm, strong, smooth and adequate kid resistant riding surface with low noise in all seasons, Receive and distribute traffic loads safely over a larger area on to the subgrade so that the stresses and strains are kept within allowable limits.

The predicted service life of a pavement depends upon design parameters such as geological factors, water table fluctuation, construction variability and prevailing conditions such as intensity of traffic, drainage and climate taken into consideration while arriving at an estimate. The assessment of the deformations or distresses and other factors that affect the service life of pavements is a complex task, because of the occurrence of events causing them being uncertain and random in nature. Hence, the subject of pavement evaluation, which deals with the above aspect, is hence of considerable significance to the management of pavements.

1.2 Pavement Types

Based on the type of material used for construction and their behavior under load, pavements may be classified into three types i.e. flexible pavement, rigid pavement and composite pavement.

A flexible pavement consists of multiple layers constructed with granular materials and protected with a bound layer called the wearing course. To serve in all weather conditions, the wearing course is constructed as an impervious layer using different types of binders e.g. modified bituminous materials. The surface course of a flexible pavement acts as a flexible layer. Under rolling wheel load, the surface layer bends like a concave shape. The surface regains its original shape as the load is removed. Repetitive application of traffic loads in different climatic conditions causes unrecoverable deformations in the pavement structure called plastic deformations.

In rigid pavements, Portland cement concrete slab is used as the wearing course. The pavement slab may be constructed with or without steel reinforcement. Under wheel load,

the top and bottom fibres of the slab experience compressive and tensile stresses, respectively. The stresses developed are resisted by beam action or flexural strength of the cement concrete slab, which bridging over soft spots or voids present in the supporting layers.

A composite pavement consists of cement concrete or cement treated granular and bituminous layers. Due to this reason, the wearing course courses constructed of these combinations of layers is neither truly flexible nor rigid.

1.3 Pavement Evaluation

The pavement evaluation of any type of pavement is very essential in order to evaluate the functional and structural characteristic of the pavement. The pavement evaluation is required for the following reasons-

a) Assessing the ride quality of the pavement and structural adequacy of the pavement structure
b) Prioritizing maintenance activity by comparing the condition with allowable values of distresses or loss of stiffness factors
c) Evolving an economical maintenance/repair strategy that best suits the distresses identified with the available funds. This may be linked to life cycle cost or long term and short term budget allocations
d) Estimating the remaining life of the pavement and developing performance/distress models for checking and updating the existing design and rehabilitation methods
e) Rescheduling maintenance/rehabilitation activities based on the above updtated predictions
f) Developing a database to serve as a reference for improving pavement maintenance management measures in future

1.4 Functional Evaluation of Pavements

The functional evaluation of pavements is concerned with the surface characteristics affecting the riding quality. Safety, comfort and serviceability and safety are main concerns such an evaluation addresses, and in this regard the surface characteristics of interest are serviceability and surface defects.

The functional evaluation of pavements is carried out for the following purposes-

a) To evaluate the surface quality of newly constructed pavement surface and adjust its pay factor
b) To monitor/determine surface conditions of pavements in terms of different forms of riding quality, by which the need for maintenance measures are assessed
c) To measure the performance of a newly laid road through its road roughness value, which is a good indicator
d) To provide engineering-based decision for allocating funds for maintenance
e) To decide a suitable maintenance option based on the type of roughness data
f) To develop deterioration models based on in-situ conditions, prevailing climatic conditions and axle load repetitions for estimating the pavement surface condition and its rate of deterioration.
g) For reviewing and revising schemes/procedures of existing pavement maintenance management system in the light of the latest models of roughness
h) For evaluating safety of pavement surface in terms of skid resistance offered over diverse geometric conditions at different operating speeds. Such studies may also be used to determine geometric inconsistencies.
i) For recording pavement performance history with the help of roughness data gathered over a period of time.

1.5 Functional Evaluation Equipments

There are various equipments for the measurement of distinct functional parameters of the pavement. The measurement of Pavement roughness can be done using various equipments such as Static Type: Vertical Staff and level, Straightedge, TRL beam, MERLIN, Dipstick profilographs, California profilographs, Rainhart profilographs; Non-Static Type: CHLOE, walker roughness device; Response type road roughness measuring (RTRRM) system: Cox meter, PCA meter, BPR roughometer, portable universal roughness device (PURD), TRRL bump integrator, ROMDAS bump integrator; High speed dynamic profilometers type (HSDP): lightweight profilometers, Network Survey Vehicle (NSV), ARRB Hawkeye etc.

Measurement of pavement texture is an important investigation by which macro and micro characteristics can be quantified; it may also be related to the condition of skidding, noise, tyre friction and roughness. Surface texture is quantified by different parameters like mean

texture depth, mean profile depth and outflow time. Static methods that can be used to measure texture includes sand patch test, grease patch test, circular texture meter, the Robo Tex surface texture profiler etc.

Different pavement distresses can be measured by using simple measuring equipments such as measuring tape or can be measured using Network Survey Vehicle (NSV) sing Hawkeye Processing Toolkit Software.

The skid resistance can be measured by using equipments such as TRL Portable skid resistance tester, Polished Stone Value Test (PSV), Dynamic Friction Tester (DFT), The VTI portable friction tester, The Micro Grip Tester, The ICC Pavement Skid Friction Test system, The TRL SCRIM, The IMAG Trailer, The Vericom Accelerometer etc.

1.6 Structural Evaluation of Pavements

Diagnosing the existing structural condition of individual layers of pavement as well as examining the overall pavement strength is termed as structural evaluation. Structural evaluation of in-service pavements is carried out to: assess the structural strength, estimate the remaining life of a pavement, determine the thickness of overlay required and to establish a pavement management system based on the performance of the road. Structural evaluation of pavements is generally carried out by two methods- (a) destructive testing (DT) (b) non-destructive testing (NDT)

In the destructive testing method, in situ pavement layers are cut open at different levels of the pavement structure to determine individual layer strengths. Other properties are determined either by in situ testing or by extracting layer samples for testing in the laboratory. As the pavement is cut at different levels and at regular intervals, the road will be heavily damaged. Huge funding would be required to restore such damaged pavements. Due to this reason, destructive testing techniques have become an unpopular practice and are generally abandoned.

In the non-destructive testing method, the pavement is not subjected to any kind of damage. Determination of strength parameters of the pavement layers is carried out without disturbing their existing conditions. Pavement surface rebound deflections are generally measured by employing different NDT equipments. This is more easy and convenient than directly measuring stress and strains. Due to this reason, many standard institutions insist on using NDT equipment for structural evaluation of pavements.

However, for physical examination, the pavement may be drilled to collect in situ samples at selected locations along the test section.

1.7 Structural Evaluation Equipments

a) Structural Evaluation by static loading- Equipments that are in use for evaluating flexible pavements under this category are: the Benkelman Beam (BB), the Lacroix deflectograph (LD) and the travelling deflectometer (TD). These equipments are very popular because of their low costs and simplicity of operation. The external loads applied are either static or moving at creep speed.

b) Structural Evaluation by Steady-State Vibratory Loading- Any NDT device that produces a sinusoidal vibration in the pavement with a dynamic force generator is categorized under this group. The most widely known devices are dynaflects and various models of the road rater. In these devices, a static load is placed over the pavement surface and a steady-state sinusoidal vibration is induced in the pavement with the help of a pulsating dynamic force generator.

c) Structural Evaluation by Impulse Loading- In this type of loading, a transient impulse force is applied on to the pavement surface and the deflected shape of the surface is measured. These equipments are capable of producing load pulses in the range of those applied by wheels of commercial vehicles. Different models of impulse loading equipment which are widely known as falling weight defelctometers (FWD) are available.

1.8 LITERATURE REVIEW

- **FUNCTIONAL EVALUATION OF PAVEMENT**

  Yi Jiang and Shuo (2005) proposed gray system modelling theory to estimate the maximum, mean and minimum International Roughness Index based on data collected on Indiana Highways at different pavement ages. It is found that large numbers of data sets are not required for gray system modelling and it discusses the effect of traffic volume on pavement riding quality. Peter Mucka (2012) developed regression models between IRI and straightedge index. Five different straightedge indexes were used to develop the model. The tests were conducted on both flexible pavements and rigid pavements.

Satish Chandra et al. (2013) developed relationship between roughness index and various distress parameters for Indian Highways. They considered four National highways to develop the relationship based on linear, non-linear regression and artificial neural networks. It is found that ANN model gives the best result taking the weightage and bias into account for predicting the IRI value. Jay N Meegoda and Shengyan Gao (2014) developed IRI model using long term pavement performance data which includes parameters as pavement age, structure number, traffic load, freezing index and annual precipitation. The optimization of the fit was achieved with the function lsqcurvefit based on the Levenberg-Marquardt algorithm in optimization toolbox of MATLAB.

Jie Li et al. (2018) proposed precise integration method (PIM) to compute IRI in a time domain which is verified to be better than ASTM code and CEN code. Considering the computational efficiency, the PIM method is 2.69 times higher than the ASTM code and 3.91 times higher than the CEN code. M. I. Hossain et al. (2019) proposed an IRI prediction model using Artificial Neural Network on long-term pavement performance database for pavements located in wet-freeze, wet-no freeze, dry freeze and dry-no freeze climatic zones. The lowest value of RMSE as 0.027 is reported in the study which predicts reasonable accurate results.

Jie Li et al. (2019) estimated the International Roughness Index using Inverse Pseudo excitation method for single source and multisource stationary random excitations. The dynamic responses of the planar vehicle model with four degrees of freedom were used. It was found that the proposed approach was independent of travelling speed, road roughness grade, and vehicle type. Hozayen and Alrukaibi (2009) proposed polynomial equations to develop relationship between road roughness, cracking, ravelling, rutting and pavement condition rating (PCR) on account of regression analysis. Best model was finally proposed based on best value of R^2.

Aguiar-Moya et al. (2011) developed IRI model using ordinary least squares (OLS). They have analysed long term pavement performance data which fits the mechanistic-empirical IRI model for flexible pavements. The model was estimated by analysing possible bias which indicated various changes in parameters affecting IRI through time. Mactutis et al. (2000) proposed models based on linear regression to predict IRI based on initial IRI reading, percentage cracking and average rut depth. The relationship is given in Eq. (1) with R^2 value of 0.71.

$$IRI = 0.597\ (IRI_{init}) + 0.0094\ (\text{fatigue percentage}) + 0.00847\ (\text{Rut Depth}) + 0.382$$

Where IRI_{init} = Initial International roughness index (m/km), Rut depth in mm

Various similar relationships between International Roughness Index and other distress parameters prevailing were developed by Mubaraki (2009) for Saudi Interurban Roads. Choi et al. (2004) developed equations for prediction of IRI for Chinese Pavement Network using regression methods and Artificial Neural Networks. They found ANN better than regression analysis. Gupta et al. (2011) developed deterioration models using regression analysis and ANN using structural and functional data collected on low volume road sections. They have used California Bearing Ratio (CBR) of subgrade, traffic volume, thickness of pavement and age of pavement as independent parameters to develop the equations. They found ANN modelling better than regression. Ceylan (2002) used ANN modelling for precise prediction of characteristic deflection profiles of flexible pavements depending upon traffic loadings.

The above literature review suggested that most of the researchers encouraged their research to develop linear regression models to predict IRI and various distress parameters. Also, they have not taken the individual weightage of each distress parameter to compare their relative importance in promoting International Roughness Index. Hence, the present study uses the individual weightage of each distress using Analytical hierarchy Process technique to develop the non linear model and ANN modelling apart from linear regression model.

- **STRUCTURAL EVALUATION OF PAVEMENT**

The pavement deflections were measured by M.S. Hoffman (1983) using Benkelman Beam, Falling weight deflectometer (FWD) and vibratory road rater and various vehicular loadings were used to check the pavement response relevant to structural evaluation on diverse loading conditions. It has been found that Falling Weight Deflectometer simulates the best structural response. The quasi-static loading of the Benkelman Beam induces the highest deflections in maximum pavements. A new procedure for measuring pavement profile, deflection, and texture from a moving vehicle has been proposed and derived by Elton and Harr (1988). The new method uses a simple mathematical algorithm to interpret distance measurements made from a rigid beam to the pavement. The algorithm is used to calculate the undeflected and deflected pavement profiles. The difference between the two profiles is the deflection caused by the load vehicle. The small size of the light spot making the distance

measurement allows the texture to be detected. Y.J. Chou (1993) suggests that instead of conducting cumbersome operations and time required to process a large non-destructive data set, computer knowledge can be used to calculate large data. S.C. Sharma et al (1996) investigated the statistical precision of annual average daily traffic (AADT) estimates resulting from short period traffic counts (SPTC). A large number of automatic traffic recorder (ATR) sites located on Minnesota's highway system are studied. Effects of various factors on estimation errors are investigated. The appropriateness of volume adjustment factors is expressed in terms of assignment effectiveness, which reflects the degree of correctness with which a sample site is assigned to an ATR group. Among several other conclusions, it is found that AADT estimation errors are very sensitive to the assignment effectiveness. The study results suggest that highway agencies should put more emphasis on sample site assignments to correct ATR groups than on the duration of count.

B.B. Reddy and A. Veeraragvan (1997) proposed that the rebound deflection, rut depth, and crack area at any time depends not only on the cumulative standard axles, but also depends on initial respective states of the pavement section. This in turn indicates that future performance of pavements depends on construction quality. It is observed that if the performance of two pavements having same magnitude of initial deflections were compared after an anticipated cumulative standard axle load repetitions, it is found that the deflection on (BM + PC) surface pavements is more than the deflection on (BM + AC) surface pavements. R.D. McQueen et al (2001) performed non destructive tests at various times on flexible pavement test items at the Federal Aviation Administration's (FAA) National Airport Pavement Test Facility (NAPTF) located at the William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The NDTs were performed with both falling weight deflectometer (FWD) and heavy falling weight deflectometer (HWD) equipment to document the uniformity of pavement and subgrade construction, as well as to acquire data on pavement response over time and increasing numbers of full-scale load repetitions. A. K. Abaza (2005) presented flexible pavement overlay design models constructed using performance curve parameters to provide an adequate overlay thickness at any given future time. The undertaken approach attempts to compensate an existing pavement structure for the loss in performance (strength) that it has endured over a specified service time. In essence, this approach is

similar to the mechanistic methods of overlay design that make a compensation for the loss in a particular strength indicator such as the commonly used deflection method. Therefore, compensation is made for the loss in performance as represented by appropriately selected performance curve parameters.

Garg, N., and Hayhoe, G. F. (2008) studied the feasibility of using Dupont Clay as low-strength subgrade, and compare pavement performance over two different subgrade types. The study showed that it is feasible to use DuPont clay as the low strength subgrade. L. Zhou et al (2010) deals with the implementation and comparison of the falling weight deflectometer (FWD) and Benkelman Beam (BB) for pavement evaluation. Field measurements were made at an in-service pavement A30 in Shanghai, China. Based on the deflections measured by FWD and BB, the exact relation between the results of FWD and BB was established. It is believed that the dynamic modulus back-calculated from FWD test results can be used as a stiffness modulus for the subgrade of new pavement construction in China. Joseph, D., and Vipulanandan, C. (2011) studied over 20 field compacted samples of two different types of soils. The correlations were developed and compared to the information in the literature. Finite element method was used to model the CBR test. A.K. Khaweir (2011) discussed the process for determining most of the important parameters used in overlay design. These parameters are traffic loading, layer thickness, stiffness modulus, interface condition, and fatigue properties. R. Nayak et al (2012) proposed a data analytic application for assessing the road pavement condition. The data analytics process includes acquisition and integration of data from multiple sources, pre-processing the data and mining the useful information from the data. The generated data mining models were able to demonstrate factors that affect pavement deflection data.

U. Sahoo et al (2014) developed performance criterion considering vertical stress over subgrade for thin surfaced rural roads using the limited data available under this study. N.R. Avinash et al (2014) presented a typical case study of an urban road network of Tumkur city, Karnataka, India. Six roads stretches of the selected road network were investigated for traffic volume, functional and structural condition in terms of CBR value of the subgrade soil, rebound deflection from Benkelman Beam Deflection (BBD) survey, International Roughness Index(IRI) using Machine for Evaluating Roughness using Low-cost Instrumentation(MERLIN) and condition

rating based on extent of cracking, patching, rutting and potholes. Modified Maintenance Priority Index (MMPI) was proposed and found to give realistic ranking of the maintenance priority requirement of the selected road network. G.R.Rada et al (2018) presented the use of traffic-speed deflection devices for the structural evaluation of pavements at the network level as part of an effort funded by the Federal Highway Administration. Highlights from three major efforts—gathering of information to identify viable devices, field trials at or near the MnROAD facility to evaluate viable devices, and data analyses to identify and select the best deflection indices.

1.9 Objectives of the Research

- To evaluate the functional evaluation parameters of study area
- To evaluate the structural evaluation parameters of study area
- To develop relationship between pavement roughness and distress parameters using for rural roads in Himachal Pradesh
- To develop relationship between Benkelman Beam Deflection and other structural parameters for rural roads in Himachal Pradesh
- To develop Rural Road Maintenance Priority Index (RRMPI) for Maintenance Prioritization in hilly region

CHAPTER 2

METHODOLOGY AND FIELD DATA COLLECTION

2.1 Selection of Road Sections

In the present study, 12 rural roads stretches each of 2.5 km length and average width of 3 metre has been selected as shown in Table 1 for conducting the pavement distress, structural and functional study. The 12 rural road sections have been selected in the vicinity of Shimla and Solan Districts of Himachal Pradesh, India. Each section (as shown in Fig. 1 and Fig. 2) has been chosen in such a way that it represents as a whole length of the stretch in terms of traffic and climatic conditions. The width of each selected rural road stretch is around 3-3.5 metre. The field data has been collected in terms of Pavement Inventory, Functional condition of roads and Structural condition of roads. Pavement inventory details include Name of the road, Category of the road viz. rural road, NH or SH, number of lanes, carriageway width of the road, surface type, maintenance and construction history of the roads, etc.

Table 1. Selected Rural Road Stretches

Road ID	Road Name	Road ID	Road Name
RR-1	Domehar-Waknaghat Road	**RR-7**	Shoghi-Heon Road
RR-2	Salogra-Ashwini Khad Road	**RR-8**	Shoghi-JaogRoad
RR-3	Kyari Bangla-Dera Road	**RR-9**	Kandaghat-Kot Road
RR-4	Basha Road	**RR-10**	Chail Road
RR-5	Khawara Chowki-Mashru Road	**RR-11**	Nain Basal Road
RR-6	Shoghi-Dooh Road	**RR-12**	Solan-Malaun Road

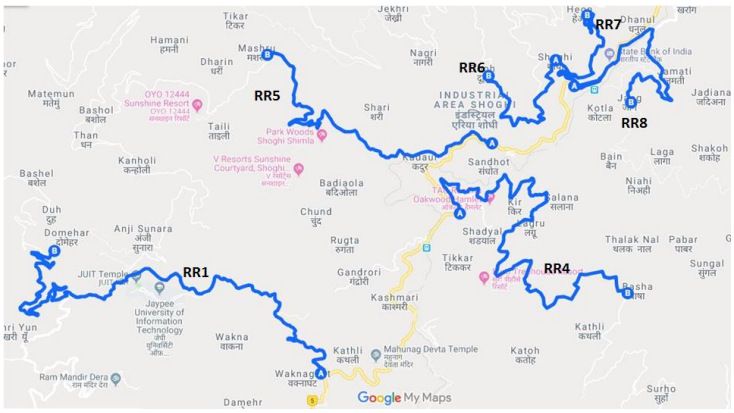

Fig. 1. Selected Rural Road Stretches

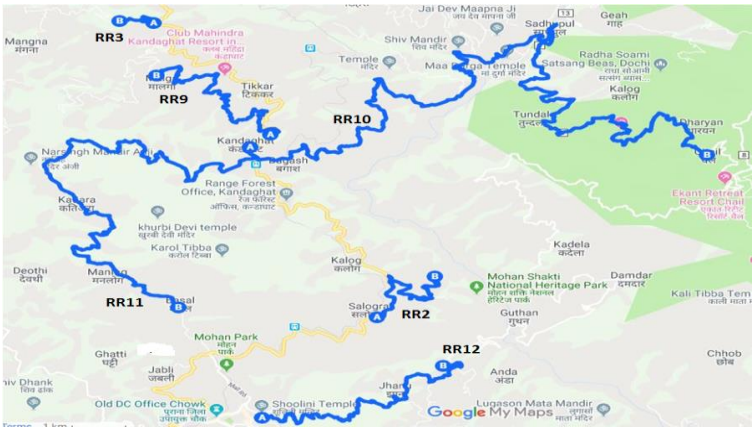

Fig. 2. Selected Rural Road Stretches

2.2 Functional Parameters Data Collection

The percentage cracking in terms of area is shown in Fig. 3. Various other prevailing distresses viz. Ravelling and Patching has also been measured using simple tape and the percentage distress of both in terms of area is shown in Fig. 4 and Fig. 5 respectively. Potholes which resemble a bowl like pavement distress has been measured in terms of volume in the present study. Each pothole is filled with a known volume of sand as shown in Fig. 6 (a) and that volume is used to quantify each particular pothole. The total volume of potholes measured on each selected rural road stretch is shown in Fig. 7. Rutting which is the longitudinal displacement in the wheel path due to the wheel load has also been studied and the mean rut depth has been measured using 3 metre straight edge as shown in Fig. 6 (d). The mean rut depth of all selected rural road stretches is shown in Fig. 8.

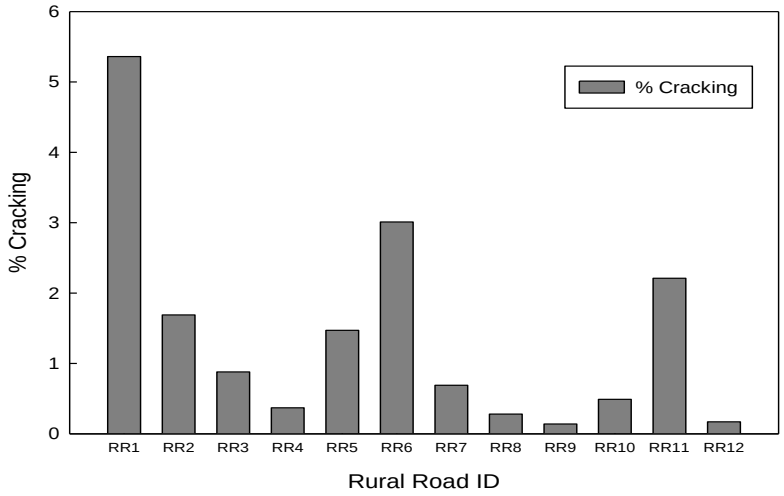

Fig. 3. Percentage Cracking of selected road stretches

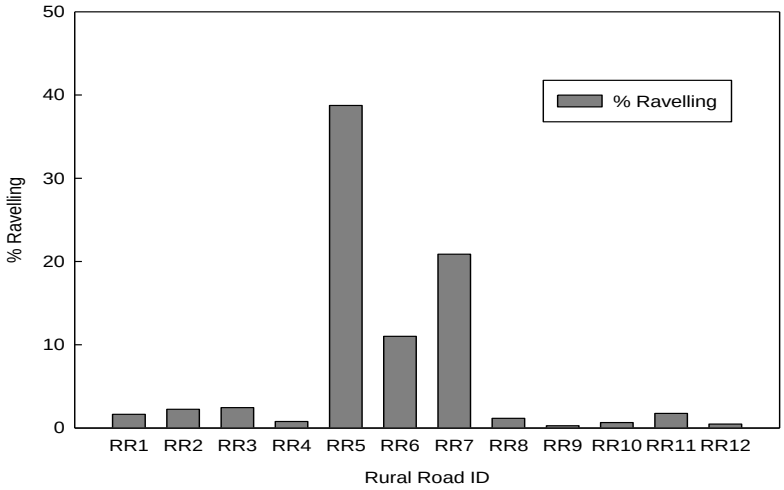

Fig. 4. Percentage Ravelling of selected road stretches

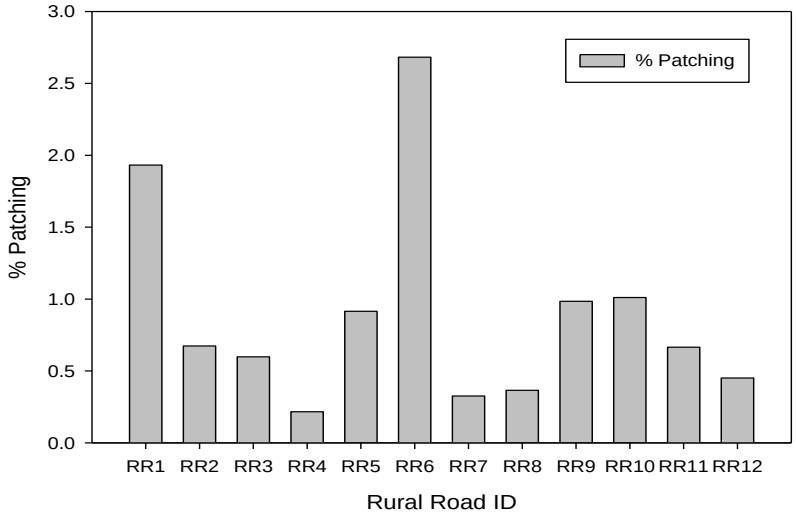

Fig. 5. Percentage Patching of selected road stretches

(a) Measurement of Volume of Pothole

(b) Sand Patch Method

(c) MERLIN for Roughness Measurement

(d) Measurement of Rutting using straight edge

Fig. 6. Measuring Various Distresses

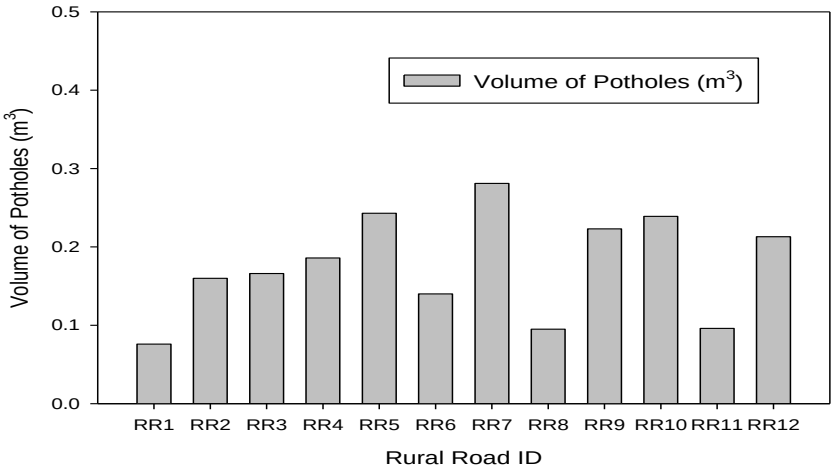

Fig. 7. Total Volume of Potholes on selected road stretches

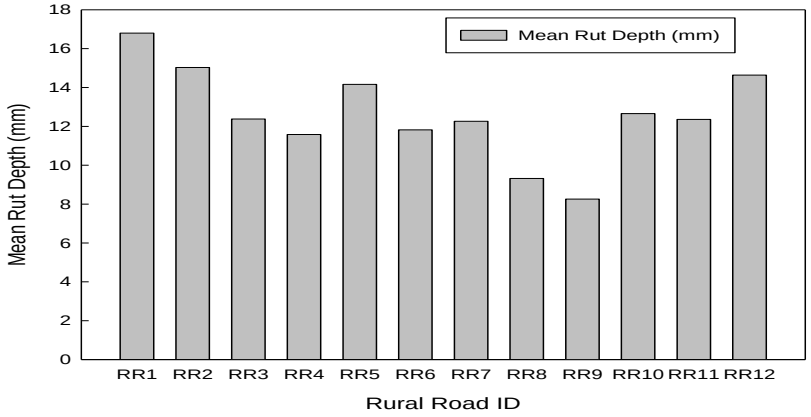

Fig. 8. Mean Rut Depth on selected road stretches

The Mean Texture Depth has also been accounted in the current study which influences the road roughness at macro level corresponding to pavement surface aggregates characteristics such as flakiness, sharpness, irregularities etc. The Mean Texture Depth has been calculated using standard test method "Sand Patch Method" given in ASTM E965 as shown in Fig. 6 (b). The mean texture depth of all selected rural road stretches is shown in Fig. 9. The International Roughness Index has been determined using MERLIN as shown in Fig. 6 (c)

(Machine for Evaluating Roughness using Low-cost Instrumentation) using standard procedure laid in MERLIN user guide. The International Roughness Index measured for all the selected rural road stretches is shown in Fig. 10.

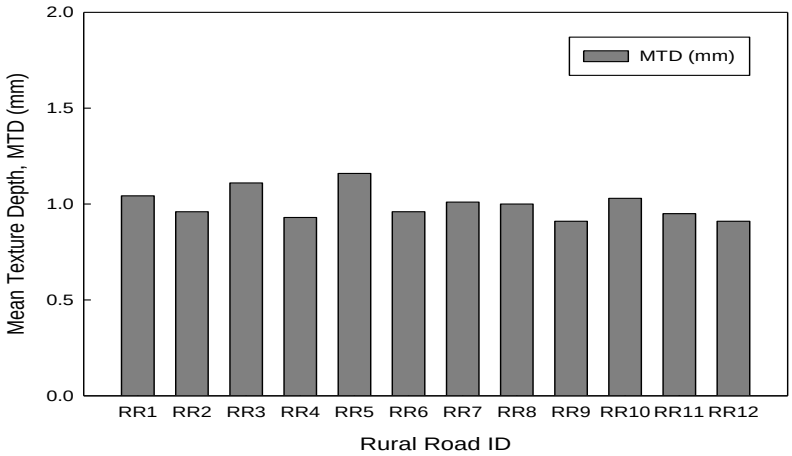

Fig. 9. Mean Texture Depth on selected road stretches

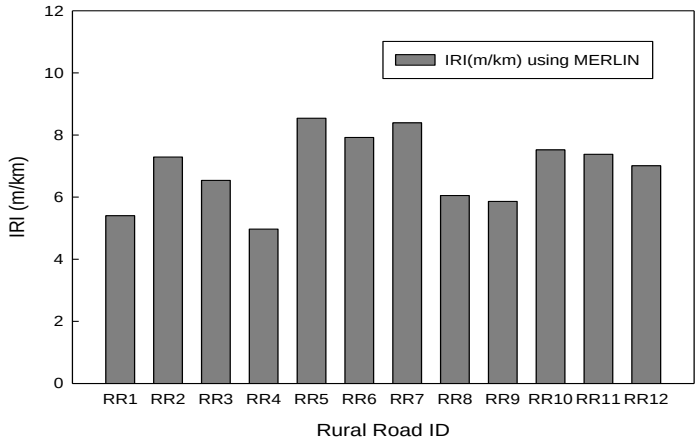

Fig. 10. IRI on selected road stretches

2.3 Structural Parameters Data Collection

Non-Destructive Benkelman Beam Deflection study was conducted on the selected sections using Benkelman Beam as shown in Fig. 11. It was decided that 10 measurement points per kilometre will be taken for data collection. Hence, 25 points per road stretch were selected to determine the characteristic deflection as per the procedure laid down in IRC: 81-1997 "Guidelines for strengthening of flexible road pavements using Benkelman Beam Deflection Technique". A standard two axle truck having rear axle load of 8.16 tonnes and tyre pressure of 5.6 kg/cm^2 was used for measurement of initial reading, intermediate

reading and final reading at each selected point 60 cm away from the pavement edge. The temperature correction was not applied because the average day temperature in the selected stretch region is less than 20^{o} C for more than four months in a year. All the deflection measurements have been made when the ambient temperature was greater than 20^{o} as suggested by IRC: 81-1997. Subgrade soil samples were taken from the test pits evaluation for determining the subgrade moisture content. These soil samples were oven dried in the laboratory for finding out the moisture content needed for applying moisture correction factor in characteristic deflection calculations. The surface characteristic deflection of all the selected 12 rural roads after applying required corrections is shown in Fig. 12.

Fig. 11. Benkelman Beam Deflection study on selected stretches

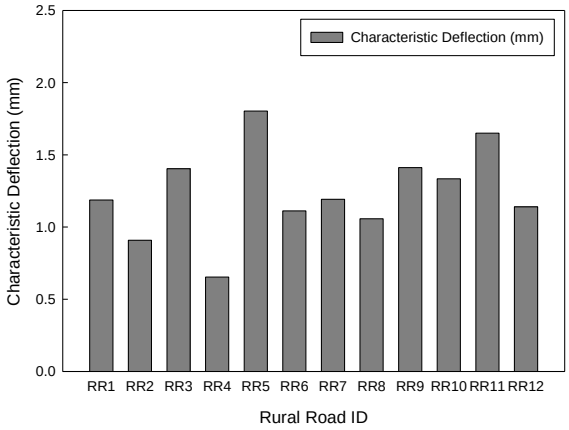

Fig. 12. Characteristic Deflection of all selected stretches

California Bearing Ratio (CBR) Test has been conducted on disturbed subgrade soil samples taken from selected 12 rural road stretches. Three subgrade soil samples were taken from each selected road stretch. All soil samples were tested in laboratory (Fig. 13) to determine the Soaked CBR value and Unsoaked CBR value. The average value of the three soil samples has been taken as shown in Table 2. The final average soaked CBR value and unsoaked CBR value of all the selected 12 rural road stretches has been shown in Fig. 14. The modulus of

subgrade reaction (K-value) has also been determined approximately corresponding to the soaked CBR value using IRC: 58-2002 "Guidelines for the design of plain jointed Rigid Pavements for highways" as shown in Table 3.

Fig. 13. California Bearing Ratio Test in Laboratory

Table 2. Unsoaked CBR and Soaked CBR Values of all soil samples

	Unsoaked CBR				Soaked CBR			
Roads	**CBR-1**	**CBR-2**	**CBR-3**	**Average CBR (%)**	**CBR-1**	**CBR-2**	**CBR-3**	**Average CBR (%)**
RR1	26.58	28.32	27.93	27.61	18.54	19.01	20.14	19.23
RR2	24.54	25.01	27.52	25.69	15.24	15.97	18.11	16.44
RR3	19.89	22.41	20.85	21.05	10.22	11.58	14.41	12.07
RR4	28.69	29.11	30.85	29.55	18.64	19.41	20	19.35
RR5	17.68	19.21	18.16	18.35	9.73	11.52	9.26	10.17
RR6	27.85	26.35	30.49	28.23	18.26	19.71	20.47	19.48
RR7	26.25	28.95	26.13	27.11	15.65	16.87	21.06	17.86
RR8	27.36	28.34	31.15	28.95	19.22	20.35	21.21	20.26
RR9	25.06	27.47	28.2	26.91	15.74	16.46	17.45	16.55
RR10	19.27	23.18	25.29	22.58	11.84	12.12	14.11	12.69
RR11	25.88	26.41	26.43	26.24	15.98	16.48	19.32	17.26
RR12	22.91	24.75	23.95	23.87	14.21	15.49	16.29	15.33

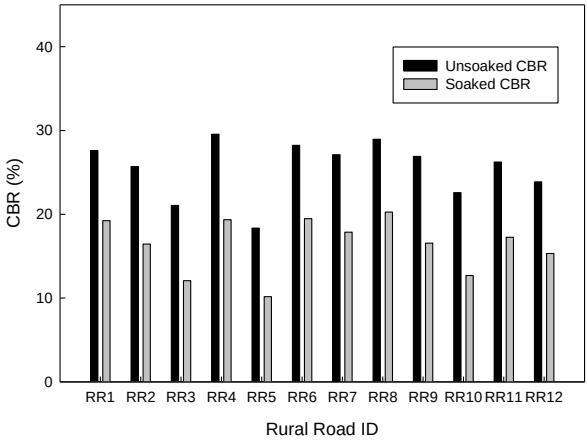

Fig. 14. Unsoaked CBR and Soaked CBR Values of selected stretches

Table 3. K-value of all selected stretches

Road ID	**RR1**	**RR2**	**RR3**	**RR4**	**RR5**	**RR6**	**RR7**	**RR8**	**RR9**	**RR10**	**RR11**	**RR12**
K-Value	6.79	6.40	5.79	6.81	5.52	6.83	6.60	6.96	6.42	5.88	6.52	6.25

Classified traffic volume surveys were conducted manually for 72 hours round the clock, by employing skilled enumerators, covering all types of vehicles viz: Buses, two-axle Trucks, multi-axle trucks, light commercial vehicles, light passenger vehicles and Two-wheelers. The traffic volume survey was done twice i.e. in lean season and in peak season, both for 72 hours as shown in Fig. 15 and Fig. 16. The traffic volume has been presented in Average Annual Daily Traffic (AADT) on all the selected rural road stretches using IRC: SP: 72-2015 "Guidelines for the design of Flexible Pavements for Low Volume Rural Roads" as shown in Fig. 17.

The age of pavement i.e. the number of years from last overlay till the year in which the Benkelman Beam study conducted was taken from DPR of the selected road sections available with PWD, Himachal Pradesh and shown in Table 4.

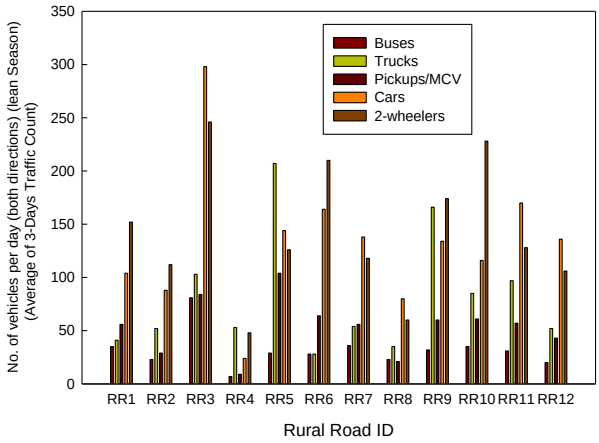

Fig. 15. Traffic Volume Survey for Lean Season

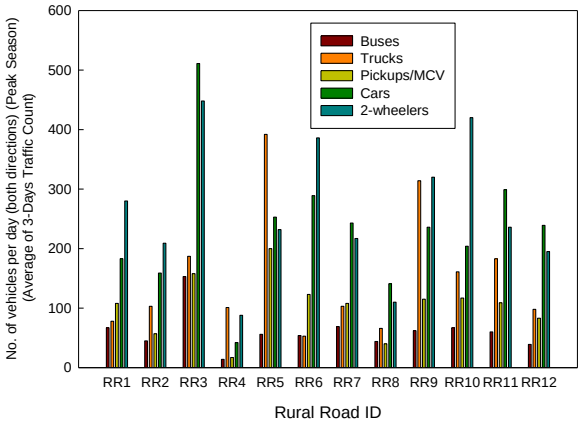

Fig. 16. Traffic Volume Survey for Peak Season

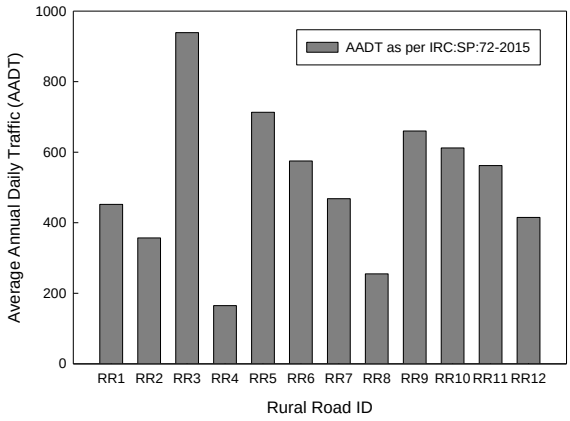

Fig. 17. Average Annual Daily Traffic of selected stretches

Table 4. Age of Pavement from last overlay (in years) of all selected stretches

Road ID	**RR1**	**RR2**	**RR3**	**RR4**	**RR5**	**RR6**	**RR7**	**RR8**	**RR9**	**RR10**	**RR11**	**RR12**
Age (years)	7	5	7	6	6	7	5	6	7	7	6	7

CHAPTER 3

DEVELOPMENT OF RURAL ROAD ROUGHNESS MODEL

3.1 Introduction

Pavements are important asset of highways which needs routine or periodic maintenance. Now days, Maintenance of highways is monitored either by functional evaluation or by structural evaluation of pavements. Functional evaluation of pavements mainly deals with the smoothness of road and the distresses present on them such as ravelling, cracking, potholes, patching, bleeding, delamination, rutting, corrugation, overlay bumps etc which can be easily visible on any highway whereas structural evaluation deals with the structural parameters of road such as deflection of road, bearing capacity etc. In view of functional evaluation, road roughness is an important parameter which is required by any highway agencies or pavement engineers to monitor the smoothness of roads. Road Roughness is also required to categorize different roads in order to strategize the maintenance priorities. Road Roughness itself is a function of various pavement distresses present on roads which proves to be hurdle in the comfort zone of road users. It also affects the vehicle operating cost when road roughness is ample. Hence, road roughness plays a vital role in the design and maintenance of highways.

The objective of the current study is to develop a road roughness model for rural road network in Himachal Pradesh which can predict the value of road roughness on the basis of various distresses present on roads. All the pavement distresses do not participate equally in the cause of road roughness. Hence, the weightage to various distresses is given based on surveys conducted using Analytical Hierarchy Approach (AHP). The weighted distress parameters have been used to develop models using linear, non-linear regression and Artificial Neural Network technique. Three models have been developed and compared with each other. The best model is finally suggested to predict road roughness value which can be very useful for pavement engineers and highway agencies to define maintenance strategies based on pavement distresses which in turn reduces the time consumed in determining road roughness value with the help of costly equipments.

3.2 Weightage Determination using AHP

Analytical Hierarchy Process is a structured tool which is useful in complex decision making. In this process, the problem is first dissolved into a hierarchy and then sub-structured into

different groups. It can solve any complex problem related to decision making which involves expert opinions and perceptions. The AHP incorporates the imagination, knowledge and experience of each individual into the analysis of any problem. It synthesizes the numerous decisions or perceptions mathematically for which the consistency of the judgements is checked to evaluate each decision and finally the output is arrived to model the concerned problem statement. In the present study, the technique of Analytical Hierarchy Process is used to determine the Weightage of different distress parameters which have a considerable effect on International Roughness Index. For this a questionnaire has been prepared as given in Appendix-1 in which various distress parameters have been compared for their relative importance. The questionnaire has been dispersed into Highway Engineers, Scientists, Academicians and Research Scholars for their individual perception based on their experience and knowledge. A total of 150 questionnaires have been distributed out of which 119 responded and used to determine the relative Weightage of various distress parameters. To check the Consistency Ratio (CR) of 119 responses Expert Choice 11 software has been used as shown in Fig. 18 and Fig. 19. If the consistency ratio of any response is more than 0.1 than that particular response has been discarded. Hence out of total 119 responses, 21 responses whose consistency ratio greater than 0.1 has been discarded and the Weightage has been calculated based on remaining 98 responses. The final weightage of each pavement distress parameter which has appreciable effect on IRI after considering 98 responses whose inconsistency is less than 0.1 are given in Table 5.

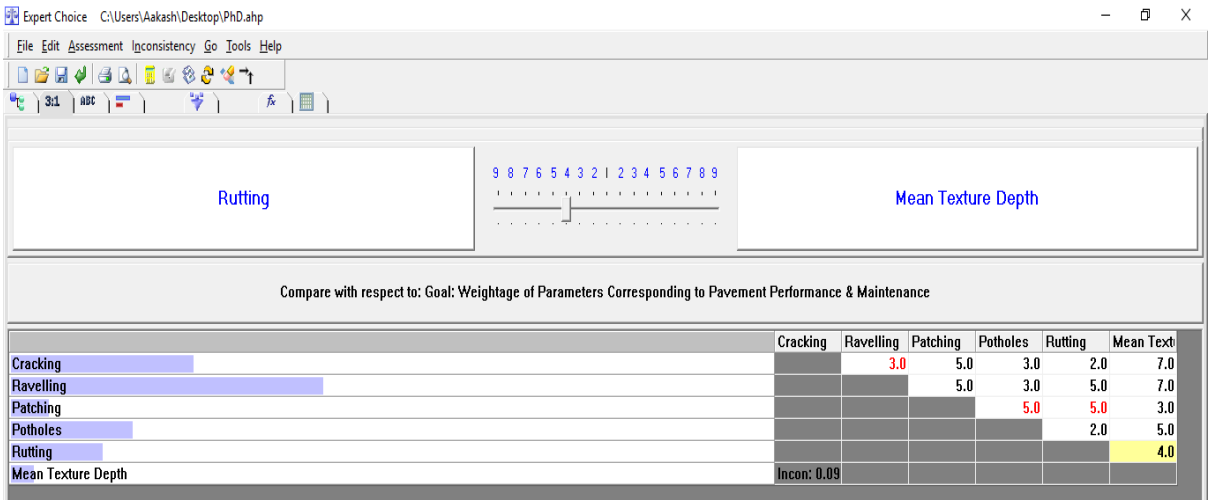
Expert Choice C:\Users\Aakash\Desktop\PhD.ahp
File Edit Assessment Inconsistency Go Tools Help
Rutting
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9
Mean Texture Depth
Compare with respect to: Goal: Weightage of Parameters Corresponding to Pavement Performance & Maintenance
Cracking Ravelling Patching Potholes Rutting Mean Text
Cracking 3.0 5.0 3.0 2.0 7.0
Ravelling 5.0 3.0 5.0 7.0
Patching 5.0 5.0 3.0
Potholes 2.0 5.0
Rutting 4.0
Mean Texture Depth Incon: 0.09

Fig. 18. Rating Input in Expert Choice Software based on various questionnaire

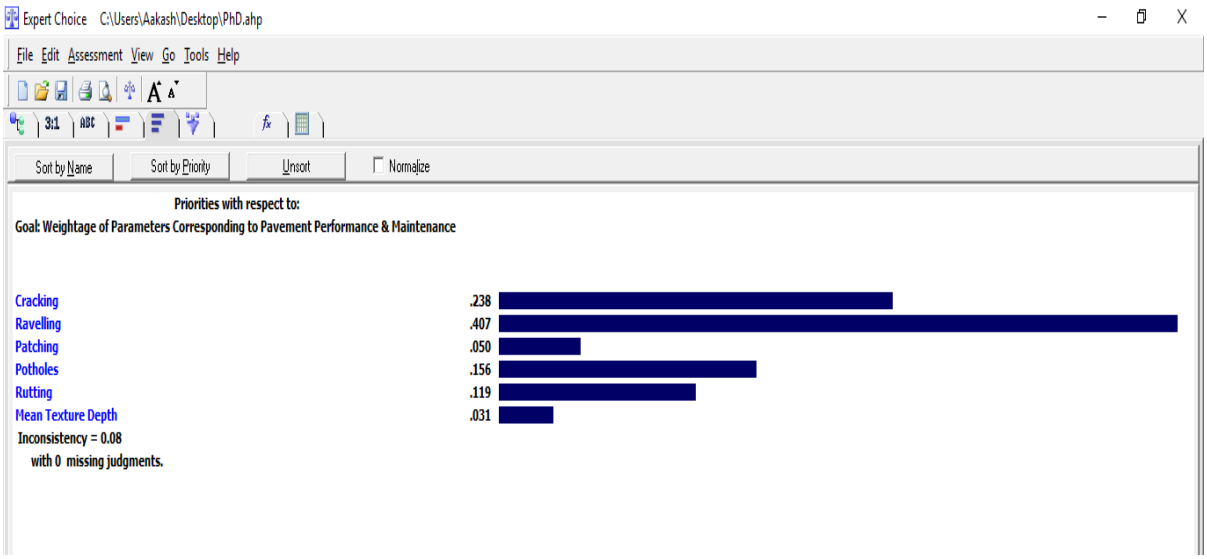

Fig. 19. Consistency Ratio Calculation using Expert Choice Software

Table 5. Weightage of Different Pavement Distresses based on AHP

Pavement Distress Type	Weightage
Cracking	20.69%
Ravelling	33.42%
Patching	5.86%
Potholes	14.22%
Mean Rut Depth/Rutting	22.27%
Mean Texture Depth	3.54%

3.3 Model Development

Efforts have been made to develop the mathematical models which can predict the value of International Roughness Index for the entire rural road network in Himachal Pradesh. Various models have been generated based on the pavement distress data collected on the selected 12 rural road sections. Pavement distresses like cracking, ravelling, patching, potholes, rutting, mean texture depth which constitutes an appreciable effect on the value of IRI on rural roads in Himachal Pradesh have been taken account for the IRI prediction model. The data collected has been divided into 60 data sets in which each data set represents data collected over a road length of 500 m which includes all the distress parameters and IRI. Each pavement distress parameter value collected during the survey has been multiplied with respective weightage factor arrived through AHP. The weighted distress data which represents actual response in pavement performance and maintenance have been used to generate models for better lucidity of International Roughness Index.

Multiple Linear Regression Model

Attempts have been made to develop a mathematical multiple linear regression model to predict the value of International Roughness Index based on weighted distress parameters. The data has been divided into test size and training size. 75% data has been used for training purpose to generate the multiple linear regression model and 25% data for testing purpose. The model have been developed using linear regression with sklearn library of PYTHON. All the distress parameters have been plotted as shown in Fig. 20 to check the correlation in between the parameters. The correlation matrix has been developed as shown in Table 6 which shows that none of the distress parameter is correlated to each other and hence all parameters are used to develop the mathematical model. The developed model is given in Eq. 1 and various statistical parameters of the models have been determined using sklearn library tools of PYTHON. The developed model was studied and tested with the actual training data and test data. The R^2 value has been determined for both training data and testing data which is 0.821 and 0.810 respectively as shown in Fig. 21. The MSE (Mean Squared Error) of training data and testing data was found to be 0.24 and 0.19 respectively.

$$IRI = C_0 + C_1*CR + C_2*RV + C_3*PC + C_4*PT + C_5*MRD + C_6*MTD \qquad \textbf{(Eq. 1)}$$

R^2=0.83

Where, C_0 = model constant, and C_1, C_2, C_3 ,C_4 ,C_5 ,C_6 = coefficients of Cracking (CR), Ravelling (RV), Patching (PC), Potholes (PT), Mean Rut Depth (MRD), Mean Texture Depth (MTD) respectively

Given as

Model Parameter	Coefficients
Intercept	C_0 = 6.191
Area of Cracking	C_1 = 0.034
Area of Ravelling	C_2 = -0.339
Area of Patching	C_3 = 0.012
Volume of Potholes	C_4 = 76.575
Mean Rut Depth	C_5 = 0.627
Mean Texture Depth	C_6 = -50.086

Where, CR = weighted area of cracking (m^2 per 1500 m^2), RV = weighted area of ravelling (m^2 per 1500 m^2), PC = weighted area of patching (m^2 per 1500 m^2), PT = weighted volume of potholes (m^3 per 1500 m^2), MRD = weighted mean rut depth (mm per 1500 m^2), MTD = weighted mean texture depth (mm per 1500 m^2)

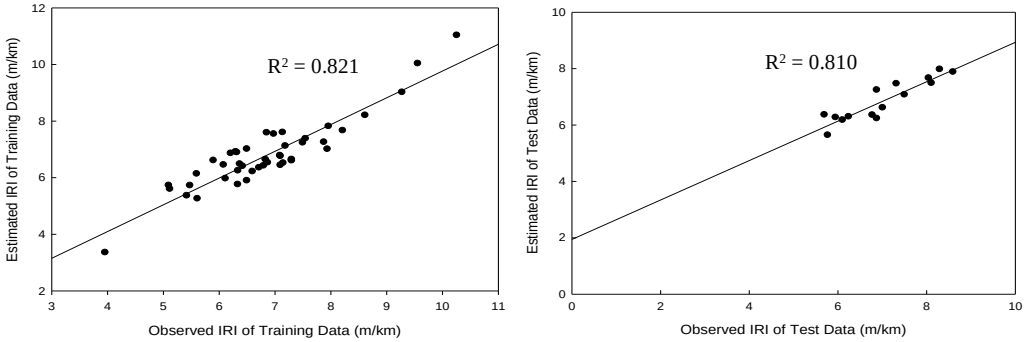
R² = 0.821
Estimated IRI of Training Data (m/km)
Observed IRI of Training Data (m/km)
R² = 0.810
Estimated IRI of Test Data (m/km)
Observed IRI of Test Data (m/km)

Fig. 21. Validation of Linear Regression Model

Table 6. Correlation Matrix

	IRI (mm)	Weighted area of cracking (m^2)	Weighted area of ravelling (m^2)	Weighted area of patching (m^2)	Weighted volume of potholes (m^3)	Weighted mean rut depth (mm)	Weighted mean texture depth (mm)
IRI (mm)	**1**	**0.34**	**0.75**	**-0.40**	**0.09**	**0.56**	**-0.01**
Weighted area of cracking (m^2)	**0.34**	**1**	**0.17**	**0.06**	**-0.17**	**0.59**	**0.19**
Weighted area of ravelling (m^2)	**0.75**	**0.17**	**1**	**-0.04**	**0.04**	**0.26**	**0.05**
Weighted area of patching (m^2)	**-0.40**	**0.06**	**-0.04**	**1**	**-0.13**	**-0.14**	**-0.01**
Weighted volume of potholes (m^3)	**0.09**	**-0.17**	**0.04**	**-0.13**	**1**	**-0.20**	**0.16**
Weighted mean rut depth (mm)	**0.56**	**0.59**	**0.26**	**-0.14**	**-0.20**	**1**	**0.11**
Weighted mean texture depth (mm)	**-0.01**	**0.19**	**0.05**	**-0.01**	**0.16**	**0.11**	**1**

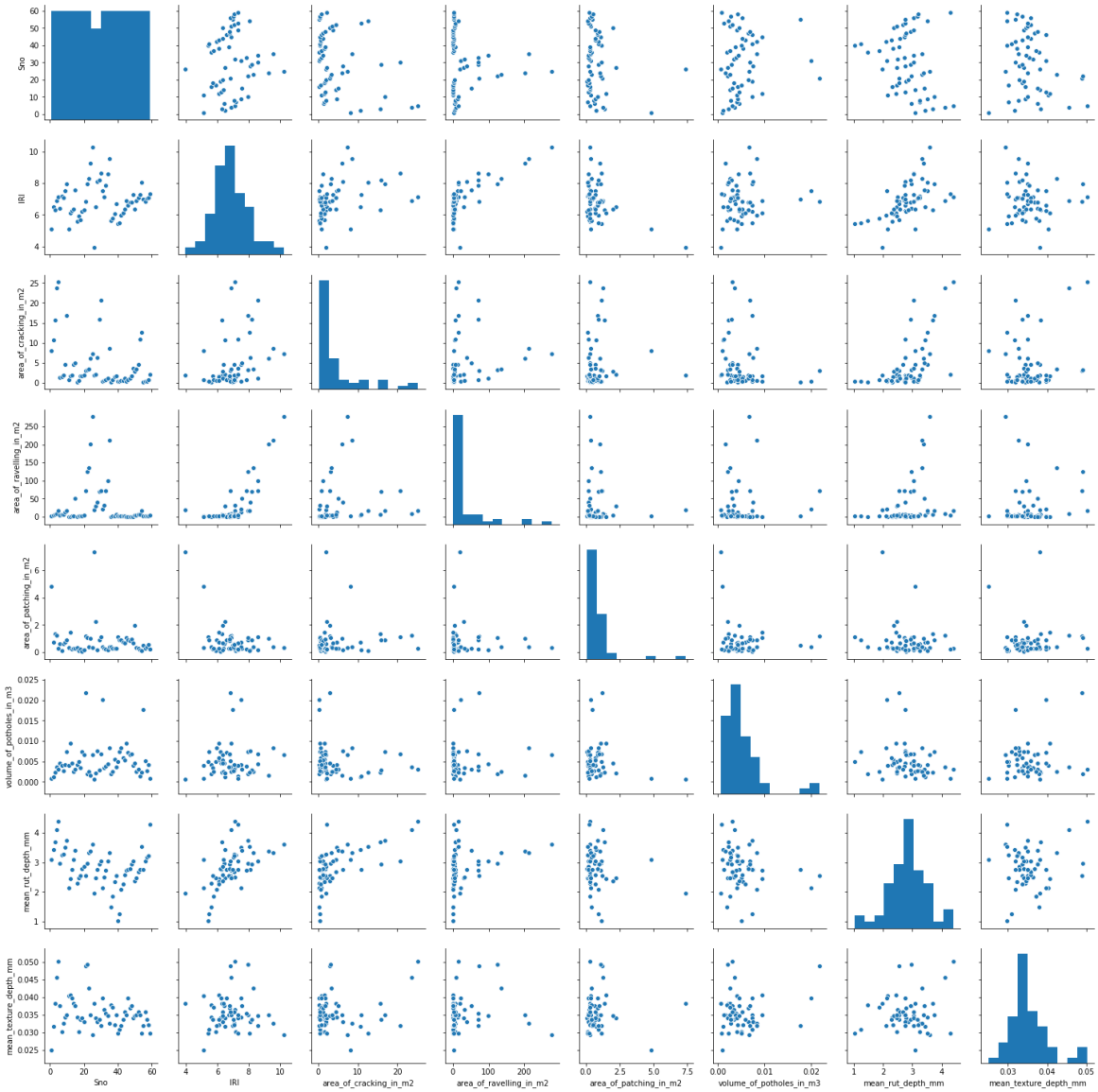

Fig. 20. Correlation Between the Distress Parameters

Non-Linear Regression Model

Another model has also been developed based on Non-Linear Regression Analysis to predict International Roughness Index corresponding to pavement distresses. Again, the model has been developed using 75% training data and 25% testing data. The developed non-linear model is presented in Eq. 2. The non-linear analysis has been done in Excel and the coefficients have been determined using SOLVER function by minimizing the Sum of Squared Residuals (SSR) depending upon the coefficients of model parameters. The R^2 value has been determined for both training data and testing data which is 0.844 and 0.837

respectively as shown in Fig. 22. The MSE (Mean Squared Error) of training data and testing data was found to be 0.22 and 0.16 respectively.

$$IRI = \beta_1 + \beta_2*(CR)^{\beta 3} + \beta_4(RV)^{\beta 5} + \beta_6(PC)^{\beta 7} + \beta_8(PT)^{\beta 9} + \beta_{10}(MRD)^{\beta 11} + \beta_{12}(MTD)^{\beta 13} \quad \textbf{(Eq. 2)}$$

Where, $\beta_1 = -227.01$, $\beta_2 = 0.031$, $\beta_3 = 0.903$, $\beta_4 = 0.108$, $\beta_5 = 0.607$, $\beta_6 = 107.315$, $\beta_7 = -0.002$ $\beta_8 = 120.981$, $\beta_9 = 0.003$, $\beta_{10} = 6.886$, $\beta_{11} = 0.168$, $\beta_{12} = -12.743$, $\beta_{13} = 0.677$

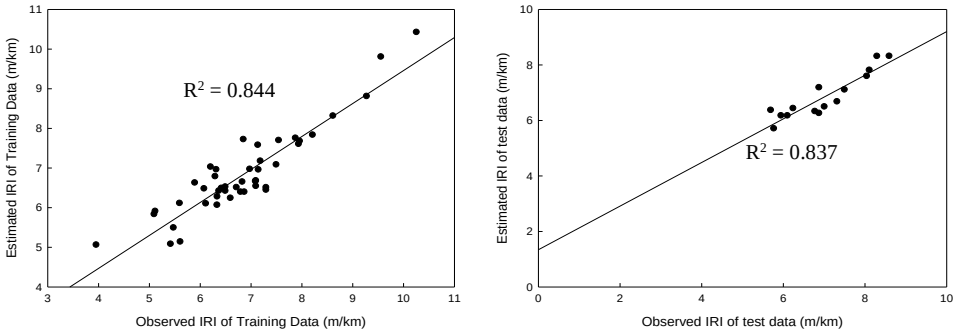
Estimated IRI of Training Data (m/km)
Observed IRI of Training Data (m/km)
R² = 0.844
Estimated IRI of test data (m/km)
Observed IRI of test data (m/km)
R² = 0.837

Fig. 22. Validation of Non-Linear Regression Model

Artificial Neural Network Modelling

Attempt has been made to use ANN to predict IRI based on various distress parameters. The model has been developed using ANN in PYTHON. Out of total data observations, 60% data has been used to train the ANN model and remaining 40% to test the model and for validation purpose to avoid any over fitting. One hundred epochs/iterations has been performed 10 times to arrive at MSE value of 0.671. The MSE value decreased drastically as the number of iterations or epochs started increasing. The equation derived from the neural network used in this model is quite complex for the simple reason that four hidden layer each having 32 neurons have been accounted as shown in Fig. 23 and dense layer neural network has been used and hence, the connection between the input and hidden layers is quite complex. Also when the number of hidden layers or nodes in the hidden layer increases the number of computations increases and due to this, more central processing unit or graphical processing unit computations are required. The result computed by increasing the number of layers has been so much nexus that the calculation of equation derived from the neural network was very complex to write down. Rectified Linear Unit (ReLu) Activation functions have been used in the development of model. ADAM optimizer has been used for deep learning of the model to update the network weights on iterative basis.

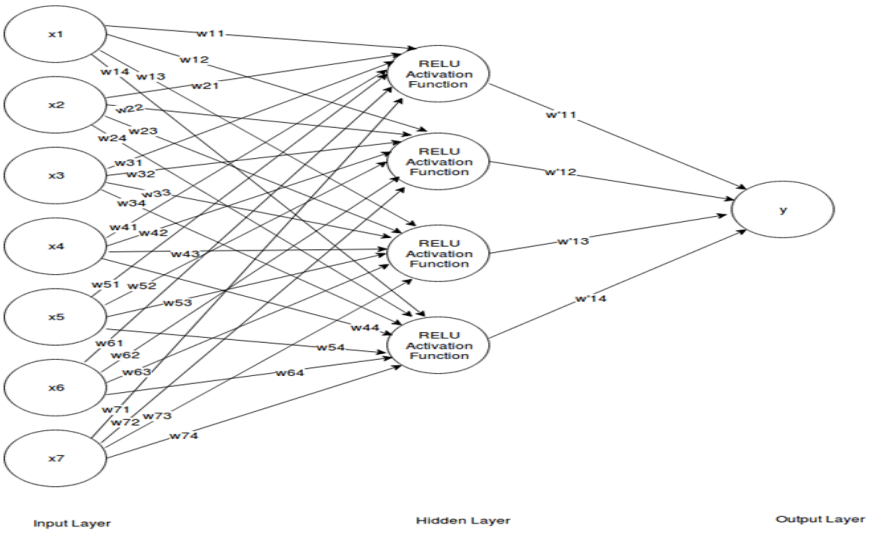

Fig. 23. Artificial Neural Network

CHAPTER 4

DEVELOPMENT OF RURAL ROAD SURFACE DEFLECTION MODEL

4.1 Introduction

Pavements are the main asset of highways which forms the backbone of the economy of any country. The performance of pavements needs to be monitored regularly to meet the service life expectancy corresponding to the intensity of traffic and prevailing environmental conditions. The proper pavement maintenance strategies lead to better economic returns. The pavement performance can be ascertained by functional and structural evaluation of pavements. Structural evaluation can be of two types, Destructive type and Non-Destructive type. In the present study, non-destructive technique has been used to evaluate the surface characteristic deflection of selected flexible rural road stretch using Benkelman Beam.

The study has been conducted on the rural roads of Himachal Pradesh which plays vital role in the development of the state. The total length of rural roads in Himachal Pradesh contributes around 81% of the total road network in the state. Out of total rural road network, 63% are tarred roads which need to be maintained timely for their better performance. These roads are not only subjected to heavy traffic loads but also suffer diverse weather of the hills throughout the year leading to heavy wear and tear.

The main objective of the present study is to eradicate the use of costly equipments such as Benkelman Beam, Falling Weight Deflectometer etc. and their cumbersome process of determining surface deflection on narrow and hilly rural roads which leads to disruption of traffic. Hence, attempts have been made to develop a mathematical model which can predict pavement characteristic deflection corresponding to traffic volume, age of pavement (number of years from last overlay), soaked CBR and Un-soaked CBR. Another model has also developed to estimate pavement surface deflection corresponding to traffic volume, age of pavement and K-value. The multiple mathematical models developed have been compared and best model is suggested based on various statistical parameters.

4.2 Model Development

Attempts has been made to develop a mathematical model to predict the characteristic pavement deflection based on Soaked CBR value, Un-soaked CBR value, Average Annual Daily Traffic (AADT) and Age of pavement from last overlay (in years). Another model has also been developed to estimate surface deflection using K-value, Average Annual Daily Traffic (AADT) and age of pavement (in years). Multiple models have been developed using linear regression model in PYTHON. The various developed models have been studied, compared and best model is suggested based on various statistical parameters such as Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE) and R^2 value.

Two models have been developed using linear regression with sklearn library of PYTHON. All the parameters have been plotted as shown in Fig. 24 and Fig. 25 to check the correlation in between the parameters. The correlation matrix has been developed as shown in Table 7 and Table 8 which shows that soaked CBR and unsoaked CBR are highly correlated to each other and hence unsoaked CBR parameter has been removed to develop the final mathematical model.

The following two mathematical models (Eq. 3 & Eq. 4) has been suggested and various statistical parameters of the models have been determined using sklearn library tools of PYTHON-

$$D_c = 0.755147 + 0.001561 * AADT - 0.025788 * Age - 0.00681 * S\_CBR \quad \text{(Eq. 3)}$$

MAE= 0.17, MSE= 0.06

RMSE= 0.19, R^2 = 0.76

$$D_c = 0.848226 + 0.001568 * AADT - 0.026334 * Age - 0.032537 * K\text{-}value \quad \text{(Eq. 4)}$$

MAE= 0.18, MSE= 0.07

RMSE= 0.21, R^2 = 0.72

Where,

D_c = Pavement Characteristic Deflection (mm)

AADT = Average Annual Daily Traffic

Age = Age of pavement from last overlay (in Years)

S_CBR = Soaked CBR value (%)

K-value = Modulus of subgrade reaction (kg/cm^3)

MAE = Mean Absolute Error

MSE = Mean Squared Error

RMSE = Root Mean Squared Error

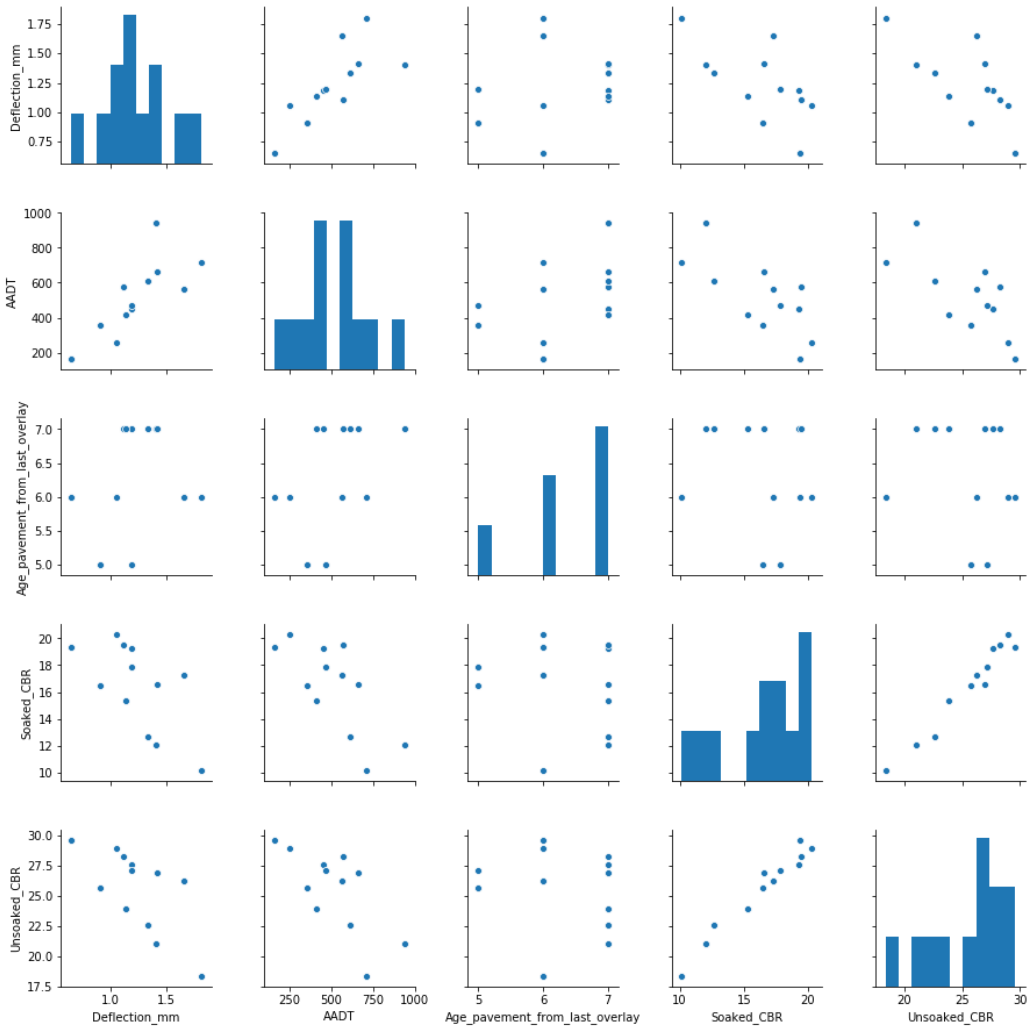

Fig. 24. Correlation between the parameters

Table 7. Correleation Matrix

	Deflection_mm	AADT	Age_pavement_from_last_overlay	Soaked_CBR	Unsoaked_CBR
Deflection_mm	1	0.75917	0.20099	-0.640273	-0.679112
AADT	0.75917	1	0.427974	-0.712567	-0.707421
Age_pavement_from_last_overlay	0.20099	0.427974	1	-0.161976	-0.157676
Soaked_CBR	-0.640273	-0.712567	-0.161976	1	0.978619
Unsoaked_CBR	-0.679112	-0.707421	-0.157676	0.978619	1

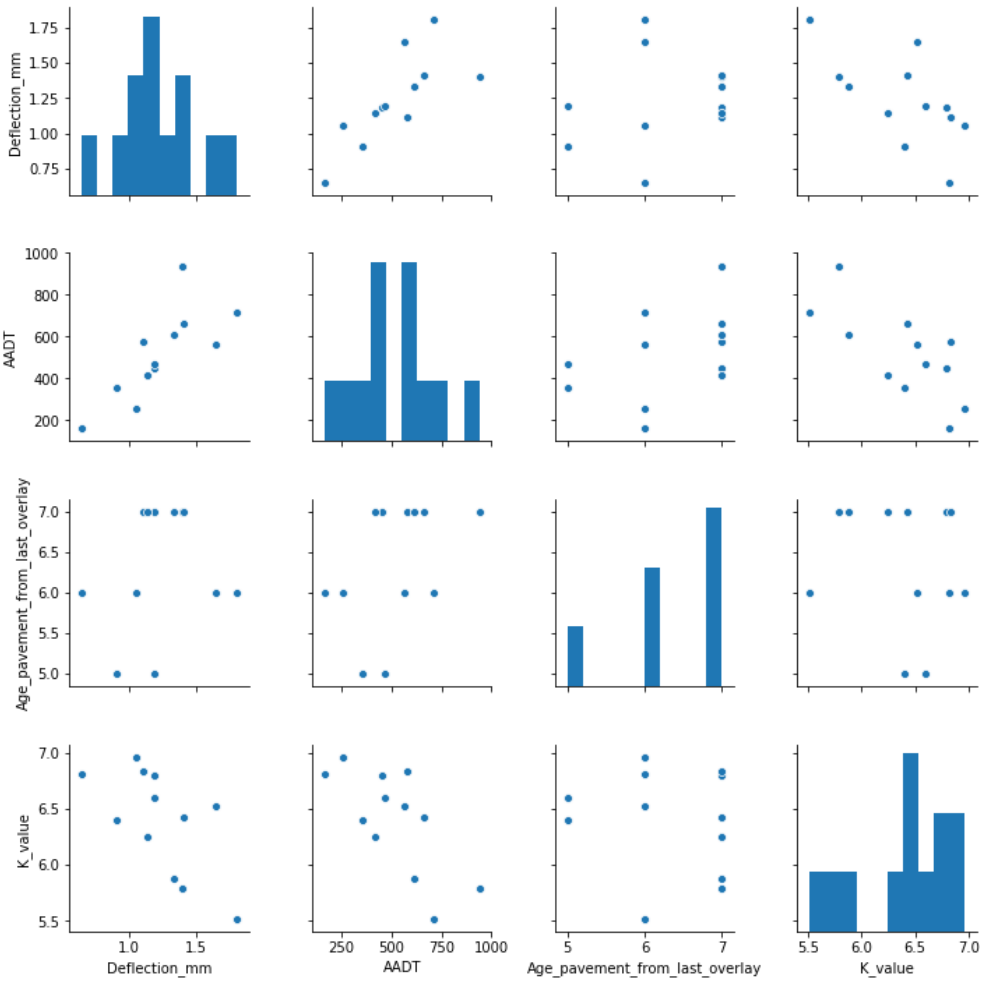

Fig. 25. Correlation between the parameters

Table 8. Correleation Matrix

	Deflection_mm	AADT	Age_pavement_from_last_overlay	K_value
Deflection_mm	1	0.75917	0.20099	-0.639065
AADT	0.75917	1	0.427974	-0.713565
Age_pavement_from_last_overlay	0.20099	0.427974	1	-0.160441
K_value	-0.639065	-0.713565	-0.160441	1

CHAPTER 5

RURAL ROAD MAINTENANCE PRIORITY INDEX

5.1 Introduction

Prioritization of roads in respect to their pavement condition is requisite in order to utilize the available road maintenance fund fruitfully. Pavement condition needs to be assessed both functionally and structurally. Functional evaluation implies the analysis of exterior road surface conditions such as International Roughness Index (IRI), pavement distresses, skid resistance etc. Pavement distresses such as cracking, ravelling, rutting, potholes, patching, etc, majorly affects the pavement condition. Pavement Roughness also affects the riding quality or riding comfort of the passengers. Apart from Functional evaluation, Structural condition of pavements also contributes a major role in determining the maintenance strategies. The characteristic deflection values determined by conducting Benkelman Beam Study helps in determining the thickness of overlay required. Modified Structural Number (MSN) has been found to be a good indicator of structural condition of pavement. The modulus of subgrade reaction (K) is also described as a structural parameter of pavements.

In this study, an attempt has been made to prioritize the rural roads in Himachal Pradesh, India regarding their functional and structural conditions, in order to provide timely maintenance as required using Rural Road Maintenance Priority Index (RRMPI). RRMPI is a function of overall functional condition index (OFCI) and overall structural condition index (OSCI) and having a scale of 0-100, in which 0 signifies worst condition of pavement and 100 signifies best condition of pavement. OFCI depends on International Roughness Index, total pavement distress and skid resistance. Hence, OFCI is a function of Functional Condition Roughness Index (FCI_{IRI}), Functional Condition Total Pavement Distress Index (FCI_{TPD}) and Functional Condition Skid Resistance Index (FCI_{SR}). Also, OSCI depends upon modified structural number (MSN) and Modulus of subgrade reaction (K-value). Hence, OSCI is a function of Structural Condition MSN Index (SCI_{MSN}) and Structural Condition K-value Index ($SCI_{K\text{-}value}$). The weightage has been given to each parameter using Analytical Hierarchy Process (AHP). The final predicted RRMPI is a useful tool for various highway agencies and engineers in order to prioritize the maintenance strategies for rural road network in Himachal Pradesh for efficient use of road maintenance fund in a genuine manner.

5.2 Analysis for Development of Rural Road Maintenance Priority Index (RRMPI)

The overall flowchart of the methodology adopted in order to develop Rural Road Maintenance Priority Index (RRMPI) is presented in Fig. 26. In the present study, 12 rural road sections have been studied in order to develop the Rural Road Maintenance Priority Index (RRMPI).

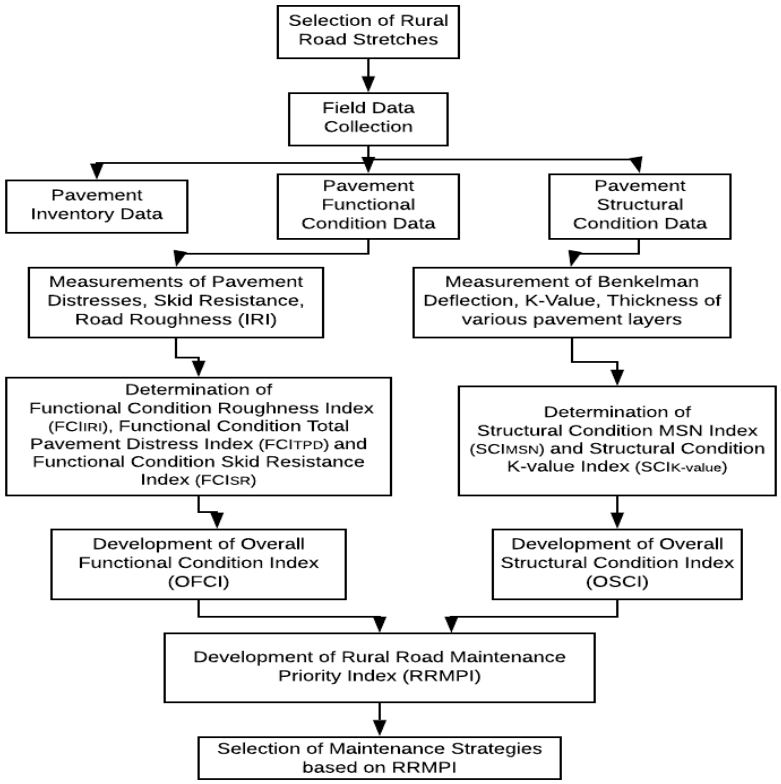
Selection of Rural Road Stretches
Field Data Collection
Pavement Inventory Data
Pavement Functional Condition Data
Pavement Structural Condition Data
Measurements of Pavement Distresses, Skid Resistance, Road Roughness (IRI)
Measurement of Benkelman Deflection, K-Value, Thickness of various pavement layers
Determination of Functional Condition Roughness Index (FCIIRI), Functional Condition Total Pavement Distress Index (FCITPD) and Functional Condition Skid Resistance Index (FCISR)
Determination of Structural Condition MSN Index (SCIMSN) and Structural Condition K-value Index (SCIK-value)
Development of Overall Functional Condition Index (OFCI)
Development of Overall Structural Condition Index (OSCI)
Development of Rural Road Maintenance Priority Index (RRMPI)
Selection of Maintenance Strategies based on RRMPI

Fig. 26. Flowchart showing detailed methodology to develop RRMPI

Functional Condition Total Pavement Distress Index (FCI_{TPD})

Various pavement distresses such as cracking, ravelling, patching, potholes, rutting etc. have been observed on the selected 12 rural road sections in Himachal Pradesh. The functional condition total pavement distress index (FCI_{TPD}) has been generated using concept of Maximum Allowable Extent (MAE). The maximum allowable extents (MAE) of different pavement distresses with their severity levels and corresponding illustrations have been given in Table 9. In the present study the threshold value for the rural road sections in Himachal Pradesh has been taken as 50. The threshold value indicates that the pavement has reached in a state where preventive and corrective measures are required for its rehabilitation.

Analytical Hierarchy Process (AHP), a complex decision making tool has also been used to give weightages to various distress parameters in order of their relative importance to each other. The AHP incorporates the imagination, knowledge and experience of each individual into the analysis of any problem. It synthesizes the numerous decisions or perceptions mathematically for which the consistency of the judgements is checked to evaluate each decision and finally the output is arrived to model the concerned problem statement. The questionnaire given in Appendix-II (PART-A) has been disseminated into Highway Engineers, Scientists, Academicians and Research Scholars for their individual perception based on their experience and knowledge. A total of 157 questionnaires have been distributed out of which 123 responded and used to determine the relative Weightages of various distress parameters. To check the Consistency Ratio (CR) of 123 responses Expert Choice 11 software has been used as shown in Fig. 27 and Fig. 28. If the consistency ratio of any response is more than 0.1 than that particular response has been discarded. Hence out of total 123 responses, 31 responses whose consistency ratio greater than 0.1 has been discarded and the Weightages has been calculated based on remaining 92 responses. The final average weightages of each pavement distress after incorporating 92 responses whose inconsistency is less than 0.1 are given in Table 11. The weightages to different severity levels of distresses has also been taken as 1, 0.75 and 0.50 to high (H), medium (M) and Low (L) Severity respectively.

Table 9. Illustration of Severity levels and MAE for different pavement distresses

Sl. No.	Pavement Distress	Severity	Illustration	Maximum Allowable Extent
1	Longitudinal & Transverse Cracking	L	Crack mean width < 3 mm	30
		M	> 3 mm and < 6 mm	25
		H	> 6 mm	15
2	Alligator Cracking	L	Few connected cracks with width between 1 to 3 mm	50
		M	Moderate connected cracks width between 3 to 6 mm	30
		H	Extensive connected mapped cracking with width > 6mm	20
3	Potholes	L	< 25 mm deep and < 200 mm wide	50
		M	25-50 mm deep and 200-500 mm wide	35
		H	> 50 mm deep and >500 mm wide	15
4	Patching	L	Patching with low distress of any type and rutting < 4mm	50
		M	Patching with moderate distress and rut depth 4-10 mm	20
		H	Patching with extensive distress and rut depth > 10 mm	15
5	Rutting	L	Rut depth <4 mm	80
		M	4-10 mm	65

		H	> 10 mm	35
6	Ravelling	L	Loss of aggregate is low and ride quality affected low	75
		M	Loss of aggregates moderate and ride quality appreciably affected	35
		H	Loss of aggregates extensive and ride quality is poor	25
7	Mean Texture Depth	L	0-0.25 mm	90
		M	0.25-0.50 mm	65
		H	> 0.50 mm	40

Table 10. Distress Index corresponding to Low, Medium and High Severity

Distress	Low Severity Index (LSI)	Medium Severity Index (MSI)	High Severity Index (HSI)
Longitudinal Cracking	**100- 50* (%L/30)**	**100- 50* (%M/25)**	**100- 50* (%H/15)**
Transverse Cracking	**100- 50* (%L/30)**	**100- 50* (%M/25)**	**100- 50* (%H/15)**
Alligator Cracking	**100- 50* (%L/50)**	**100- 50* (%M/30)**	**100- 50* (%H/20)**
Potholes	**100- 50* (%L/50)**	**100- 50* (%M/35)**	**100- 50* (%H/15)**
Patching	**100- 50* (%L/50)**	**100- 50* (%M/20)**	**100- 50* (%H/15)**
Rutting	**100- 50* (%L/80)**	**100- 50* (%M/65)**	**100- 50* (%H/35)**
Ravelling	**100- 50* (%L/75)**	**100- 50* (%M/35)**	**100- 50* (%H/25)**
Mean Texture Depth	**100- 50* (%L/90)**	**100- 50* (%M/65)**	**100- 50* (%H/40)**

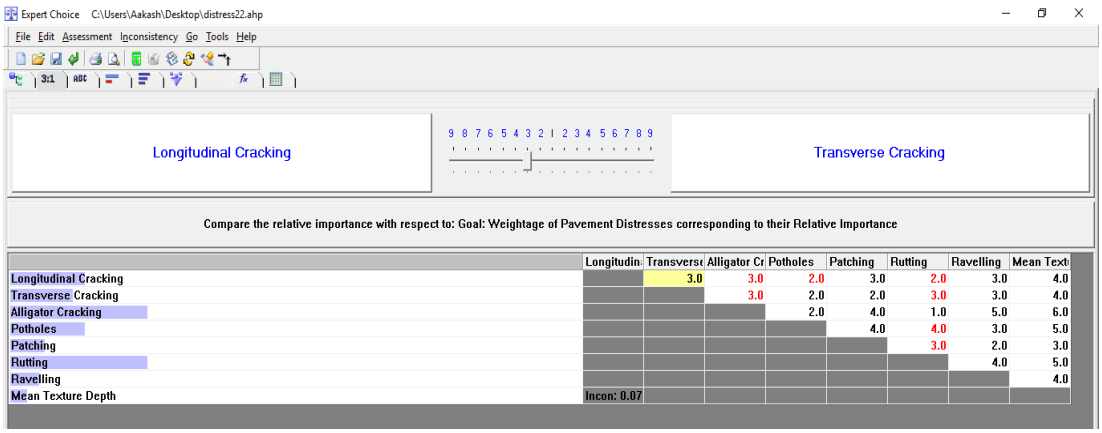

Fig. 27. Expert Choice 11 software using questionnaire data

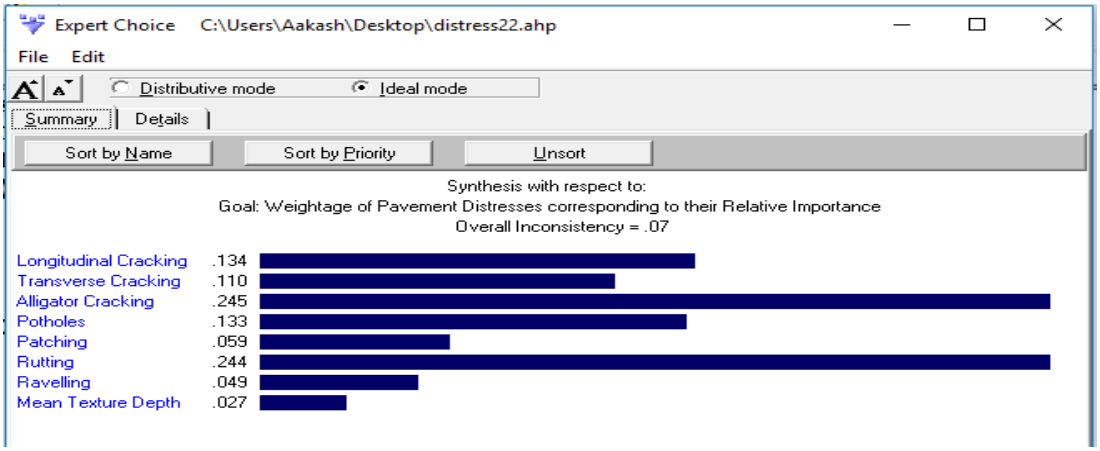

Fig. 28. Sample weightages determined using a questionnaire in Expert Choice 11 software

Table 11. Weightages determined using AHP Expert Choice 11 software

Pavement Distress Type	Weightage (W_i)
Longitudinal Cracking	0.15
Transverse Cracking	0.12
Alligator Cracking	0.23
Potholes	0.14
Rutting	0.22
Ravelling	0.05
Patching	0.07
Mean Texture Depth	0.02

The distress index calculated using equations given in Table 10 are subjected to a minimum value of 0 and maximum value of 100 where %L, %M and %H indicated the percentage of distress area measured using simple measuring tape (longitudinal cracking, transverse cracking, alligator cracking, patching, and ravelling) with low, medium and high severity respectively.

Percent of rut depth and potholes within each severity is measured using the following equation-

(Number of ruts or potholes within each severity/15)* 100

Percent of mean texture depth within each severity is measured using the following equation-

{Number of sand patch test results (test conducted subjected to 15 sample per 100 m length of road and 3.5 m wide) within each severity/Total Number of test conducted} * 100

Further, each pavement distress index has been calculated by incorporating the weight factors of different severity levels. The distress index for each distress of pavement can be calculated using equation (5).

$$\text{Each Pavement Distress Index (PDI)} = \frac{\lfloor 0.50 * LSI + 0.75 * MSI + 1.0 * HSI \rfloor}{\lfloor 0.50 + 0.75 + 1.0 \rfloor} \quad (5)$$

The functional condition Total Pavement Distress has been calculated by incorporating the weightages determined by Analytical Hierarchy Process (AHP) using Expert Choice 11 software given in Table 11. The functional condition total pavement distress has been determined by using equation (6).

$$\text{FCI}_{\text{TPD}} = \sum w_i * PDI \quad (6)$$

Where, w_i = weightages given in Table 11

PDI = Each Pavement Distress Index corresponding to longitudinal cracking, transverse cracking, alligator cracking, potholes, patching, rutting, ravelling and mean texture depth calculated from equation (5).

Functional Condition Roughness Index (FCI_{IRI})

The functional condition roughness index has been determined by correlating the International Roughness Index (IRI) and Ride Comfort Rating (RCR) as given by non-linear regression equation (7). The International Roughness Index (IRI) has been calculated using MERLIN on the selected rural road sections. The Ride Quality Rating (RCR) survey has been done by a panel of four members on the selected road sections and their average rating depending upon the guidelines given in Table 12 and their personal perception has been considered in the study.

$$FCI_{IRI} = RCR = -606.40 + 848.80 * (IRI)^{(-0.14)} \quad (R^2 = 0.85) \qquad (7)$$

Where, RCR = Ride Quality Rating subjected to Minimum value 0 and Maximum value 100

IRI = International Roughness Index in (m/km)

Table 12. Guidelines for Panel Conducting Ride Comfort Rating (RCR)

Ride Comfort Rating (RCR)	Section Evaluation	Description
0-20	Very Poor	More than 75% of the pavement section is drastically affected by presence of large, deep and wide cracks and potholes. The riding quality/comfort is drastically affected and speed is reduced. The pavement surface possesses water logging problem in rainy season.
20-40	Poor	About 50% of the pavement surface is affected with deep and wide cracks, large potholes, free flowing speed reduced drastically and other type of high severity distresses are prevailing on the section surveyed.
40-60	Fair	Ride comfort quality is moderately affected which affects high-speed flow of traffic. Moderate alligator cracking, patching, rutting observed over the surface.
60-80	Good	Riding Comfort may be good but apart from it, very low severity visible micro-cracks and initiation of rutting or ravelling over the surface observed.
80-100	Very Good	Conditions similar to a newly constructed pavement having smooth surface and no visible pavement distress on the surface.

Functional Condition Skid Resistance Index (FCI_{SR})

The skid resistance has been obtained by using skid resistance pendulum testing machine. The scale of skid resistance pendulum testing machine is between 0-100 in which higher value depicts a good pavement surface with high skid resistant surface and low value depicts that pavement surface is slippery and skid resistant is low. Hence, the functional condition skid resistance index (FCI_{SR}) has been taken directly from the result obtained by the skid resistant pendulum testing machine.

Structural Condition MSN Index (SCI_{MSN})

The best indicator of structural condition of pavement is its structural number which depends on the rebound deflection of the surface of the pavement, layer coefficients, and thickness composition of each layer of pavement. The characteristic deflection of the surface of

pavement has been measured using Benkelman beam as per the procedure recommended in IRC 81:1997. AASHTO test developed the concept of Structural Number (SN) which is the indicator of strength of any pavement. Further the Structural Number has been modified after incorporating the California Bearing Ratio (CBR) of subgrade and defined as Modified Structural Number (MSN). The Modified Structural Number is calculated using equation (8).

$$MSN = SN + 3.51\ (\log_{10} CBR) - \ 0.85(\log_{10} CBR)^2\ - 1.43 \qquad (8)$$

Where, $SN = \ \sum_{i=1}^{n} a_n\ *\ t_n$

Where, a_n = layer coefficients of n layers, t_n = thickness of n layers of pavement in inches

CBR = California Bearing Ratio of pavement subgrade (%)

The layer coefficients of different layers as prescribed by Central Road Research Institute, New Delhi have been used in the present study. The structural condition MSN Index has been determined using equation (9).

$$SCI_{MSN} = \left(\frac{MSN}{SN_{effective}}\right) X\ 100 \qquad (9)$$

Where, $SN_{effective} = 3.2 *$

$(Characteristic\ Deflection\ in\ mm\ using\ Benkelman\ Beam) - 0.63$

MSN = Modified Structural Number from equation (8)

Structural Condition K-Value Index ($SCI_{K\text{-}value}$)

The modulus of subgrade reaction is an important structural parameter which indicates the structural adequacy of the concerned pavement. The K-value can be obtained by conducting plate bearing test but the test being too expensive, hence the required K-value for the selected 12 rural road sections has been obtained using the relationship given between soaked CBR and K-value in IRC 58-2015. The range of K-value for a soaked CBR range of 2% - 100% is 21 – 220 MPa/m. Since, the subgrade CBR value of upto 50% is good for rural road sections in Himachal Pradesh; hence, the subgrade CBR value of 50% is taken as the upper limit and the structural condition K-value index has been obtained by normalizing it in range of 0-100 by using the formula given in equation (10), where high value of index depicts stiffer and

good structural adequacy of pavement whereas low value directs a poor structural adequacy of pavement.

$$SCI_{K\text{-}value} = 100 * \frac{(K_{value} - 21)}{(140-21)} \quad (10)$$

Development of Overall Functional Condition Index (OFCI) and Overall Structural Condition Index (OSCI)

The overall functional condition index (OFCI) is dependent on Functional Condition Total Pavement Distress Index (FCI_{TPD}), Roughness Index (FCI_{IRI}) and Skid Resistance Index (FCI_{SR}) where as overall structural condition index (OSCI) depends upon Structural Condition MSN Index (SCI_{MSN}) and K-Value Index ($SCI_{K\text{-}value}$). Hence, weightages need to be determined for various parameters depending upon OFCI and OSCI to develop respective indexes. The same sample data of 92 responses has been used corresponding to questionnaire given in Appendix-II (part-B). Expert Choice 11 software has been used and the structured tree of OFCI and OSCI has been shown in Fig. 29. The dynamic sensitivity of nodes has also been done using the software shown in Fig. 30. The average weightage of 55%, 30% and 15% has been obtained for OFCI parameters of Total Pavement Distress Index (FCI_{TPD}), Roughness Index (FCI_{IRI}) and Skid Resistance Index (FCI_{SR}) respectively and the average weightage of 65% and 35% has been assigned to OSCI parameters of Structural Condition MSN Index (SCI_{MSN}) and K-Value Index ($SCI_{K\text{-}value}$) respectively. Hence, the Overall Functional Condition Index (OFCI) and Overall Structural Condition Index (OSCI) has been determined using equations (11) and (12) respectively.

$$OFCI = 0.55 * FCI_{TPD} + 0.30 * FCI_{IRI} + 0.15 * FCI_{SR} \quad (11)$$

Where, FCI_{TPD} = Functional Condition Total Pavement Distress Index

FCI_{IRI} = Functional Condition Roughness Index

FCI_{SR} = Functional Condition Skid Resistance Index

$$OSCI = 0.65 * SCI_{MSN} + 0.35 * SCI_{K-value} \quad (12)$$

Where, SCI_{MSN} = Structural Condition MSN Index

$SCI_{K\text{-}value}$= Structural Condition K-Value Index

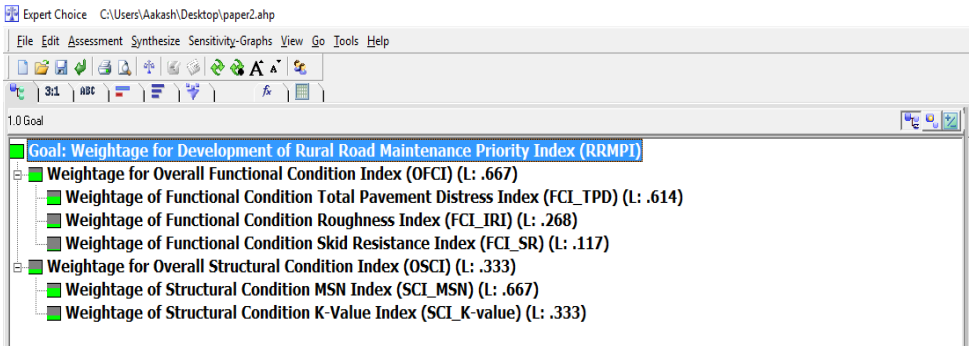
Expert Choice C:\Users\Aakash\Desktop\paper2.ahp
File Edit Assessment Synthesize Sensitivity-Graphs View Go Tools Help
1.0 Goal
Goal: Weightage for Development of Rural Road Maintenance Priority Index (RRMPI)
Weightage for Overall Functional Condition Index (OFCI) (L: .667)
Weightage of Functional Condition Total Pavement Distress Index (FCI_TPD) (L: .614)
Weightage of Functional Condition Roughness Index (FCI_IRI) (L: .268)
Weightage of Functional Condition Skid Resistance Index (FCI_SR) (L: .117)
Weightage for Overall Structural Condition Index (OSCI) (L: .333)
Weightage of Structural Condition MSN Index (SCI_MSN) (L: .667)
Weightage of Structural Condition K-Value Index (SCI_K-value) (L: .333)

Fig. 29. Weightage determination using Expert Choice 11 software

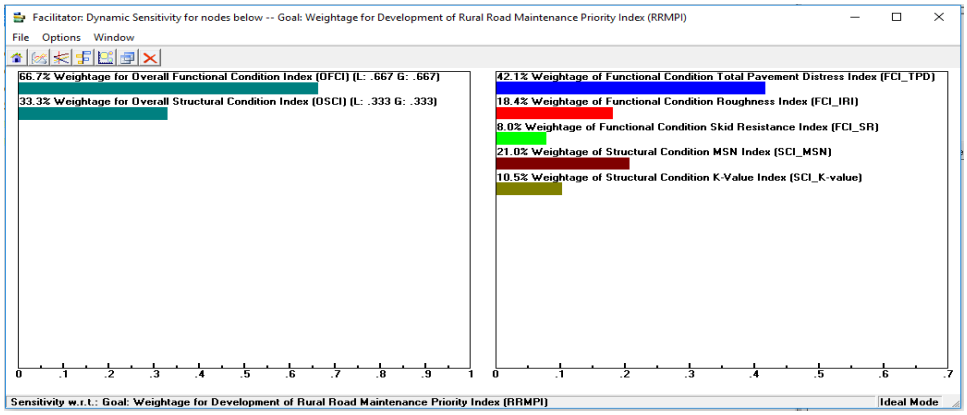
Facilitator: Dynamic Sensitivity for nodes below -- Goal: Weightage for Development of Rural Road Maintenance Priority Index (RRMPI)
File Options Window
66.7% Weightage for Overall Functional Condition Index (OFCI) (L: .667 G: .667)
33.3% Weightage for Overall Structural Condition Index (OSCI) (L: .333 G: .333)
42.1% Weightage of Functional Condition Total Pavement Distress Index (FCI_TPD)
18.4% Weightage of Functional Condition Roughness Index (FCI_IRI)
8.0% Weightage of Functional Condition Skid Resistance Index (FCI_SR)
21.0% Weightage of Structural Condition MSN Index (SCI_MSN)
10.5% Weightage of Structural Condition K-Value Index (SCI_K-value)
Sensitivity w.r.t.: Goal: Weightage for Development of Rural Road Maintenance Priority Index (RRMPI)
Ideal Mode

Fig. 30 Dynamic Sensitivity of nodes using Expert Choice 11 software

Development of Rural Road Maintenance Priority Index (RRMPI)

The Rural Road Maintenance Priority Index (RRMPI) has been developed which is based on overall functional condition index (OFCI) and overall structural condition index (OSCI) which has been determined using equations (vii) and (viii) respectively. The weights have been assigned to functional parameters and structural parameters of pavement separately in order to articulate the final Rural Road Maintenance Priority Index (RRMPI) for best results. The weights have been determined using Expert Choice 11 software based on Analytical Hierarchy Process as shown in Fig. 30 using questionnaire given in Appendix-II (PART-B). After processing 92 questionnaires, the average weightage of 60% has been assigned to functional parameters and 40% to structural parameters. Hence, final RRMPI has been determined using equation (13).

$$RRMPI = 0.6 * (OFCI) + 0.4 * (OSCI) \qquad (13)$$

Where, OFCI and OSCI are overall functional condition index and overall structural condition index respectively.

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Results from Rural Road Roughness Model

The percentage cracking is found to be lowest (0.14%) in RR9 whereas it is highest in rural road stretch of RR1 with 5.36% as shown in Fig. 3. Also, the percentage ravelling is found to be lowest in RR9 with 0.28% and shown a significant effect in RR5 with 38.74% as shown in Fig. 4. The distress patching is found to be very low on all the roads in a range of 0.22% - 2.68% as shown in Fig. 5. The highest percentage patching is found to be on RR6. The total volume of potholes measured through replacing a known volume of sand with the pothole bowl is found to be significant on RR7 with 0.28 m^3 of volume (Fig. 7). However, least volume of pothole is found to be on RR1 with 0.076 m^3 of volume (Fig. 7). Also, the mean rut depth is found to be highest on RR1 with a value of 16.8 mm and RR9 secures lowest 8.26 mm mean rut depth as shown in Fig. 8. The mean texture depth obtained by sand patch method is found to be significant on RR5 with 1.16 mm (Fig. 9). The International Roughness Index derived by MERLIN is obtained by taking the average of four reading per 500 m stretch and found to be highest on RR5 with 8.5 mm/km whereas it is lowest on RR4 with 5.9 mm/km as shown in Fig. 10.

The weightage given to various distresses as shown in Table 5 using Analytical Hierarchy Process shows that as per the experts cracking has greater importance relative to other distress parameters and mean texture depth leads to least important parameter in pavement performance and maintenance.

The R^2 value in linear regression model for both training data and testing data is 0.821 and 0.810 respectively which shows a good correlation as shown in Fig. 21. The MSE (Mean Squared Error) of linear regression model for training and tested data is found to be 0.24 and 0.19 respectively which shows estimated values of IRI using this model are very close to the observed values of IRI. The R^2 value in non linear regression model for both training data and testing data is 0.844 and 0.837 respectively which also shows a good correlation as shown in Fig. 22. The MSE of Non linear regression model for training and tested data is found to be 0.22 and 0.16 respectively whereas the MSE value of model developed using Artificial Neural Network is found to be very high as 0.671.

6.2 Results from Rural Road Surface Deflection Model

The Benkelman beam study conducted on all the twelve selected rural road stretches shows that RR5 has the most characteristic deflection value of 1.8 mm and RR4 has the least deflection value of 0.65 mm (Fig. 12). Hence RR5 needs to be maintained first out of the twelve selected stretches. The average unsoaked CBR value of RR5 is 18.35% (Table. 2) which is least among all the selected roads which show poor subgrade strength. The average annual daily traffic (AADT) of 940 is maximum on RR3 followed by RR5 with an AADT of 713 (Fig. 17), hence the traffic volume on RR5 has significant contribution to the pavement deflection value of 1.8 mm. The age of pavement from last overlay is in the range of 5-7 years. The two mathematical models developed are evaluated using statistical parameters such as Mean Absolute Error (MAE), Mean Squared Error (MSE) and Root Mean Squared Error (RMSE) as shown in Eq. 3 and Eq. 4. The model developed in Eq. 3 is found to be better than model developed in Eq. 4 depending upon better RMSE value of 0.19 as compared to 0.21 of Eq. 4. The R^2 value of Eq. 1 is 0.76 which shows a good fit as compared to 0.72 of Eq. 4.

6.3 Results from Rural Road Maintenance Priority Index (RRMPI)

The individual functional condition indexes of total pavement distress, International Roughness Index, Skid Resistance and structural condition indexes of Modified structural number and K-value parameter has been shown in Fig. 31. The overall functional condition index (OFCI), overall structural condition index (OSCI) and The Rural Road Maintenance Priority Index (RRMPI) has been determined for all the 12 selected rural road sections in the vicinity of Shimla and Solan districts, Himachal Pradesh which has been depicted in Fig. 32.

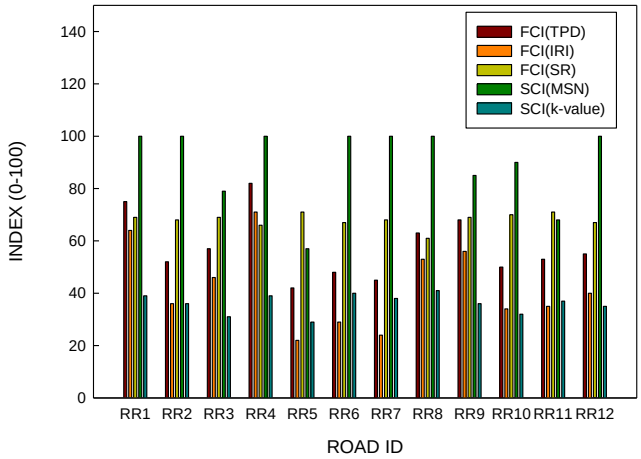

Fig. 31 Individual Functional and Structural Indexes

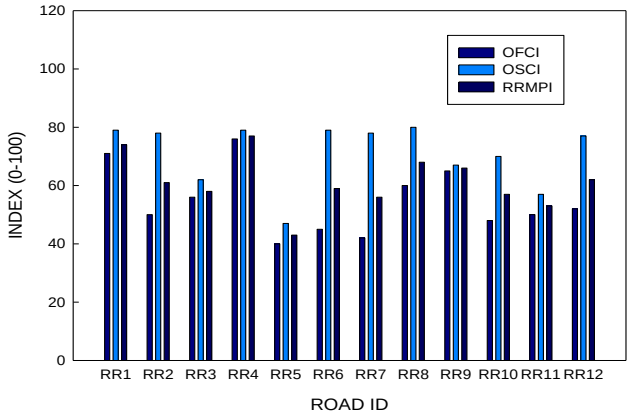

Fig. 32 OFCI, OSCI and RRMPI Indexes of selected Rural Roads

CHAPTER 7

CONCLUSIONS

7.1 Conclusions

In the present study, 12 rural road stretches of Himachal Pradesh has been selected for the development of International Roughness Index prediction model. Various mathematical models have been generated to predict the value of International Roughness Index based on various distress parameters which are available and causes major affect on the roughness of rural roads present in Himachal Pradesh. The models have been developed using linear regression, non-linear regression and Artificial Neural Networks which depicts that linear regression model and non-linear regression model gives very effective results when compared to Artificial Neural Network. The R^2 value in case of linear model and non-linear model for tested data is found to be 0.810 and 0.837 respectively which shows a very good correlation between the observed IRI and predicted IRI. Both the models are very accurate; however, the R^2 value of non-linear model is on upper hand which is 3.34% more than that of linear regression model. Hence, it is suggested that non-linear model is more reliable than linear regression model. The MSE values of linear regression model, non-linear regression model and ANN model for tested data are found to be 0.19, 0.16 and 0.67 respectively which again shows that linear regression and non-linear regression models are predicting far better results when compared to ANN model. It is due to because the number of data observations is quite less required for data training in Artificial Neural Network modelling. Hence, it is suggested that more number of data sets can be collected for better results of Artificial Neural Network model for further research scope on rural roads of Himachal Pradesh. Also, in the present study, conventional method of data collection has been used such as measuring roughness through MERLIN, measurement of cracking area, ravelling area etc through simple measuring tape. Hence, to expedite the process of data collection some modern technique such as Network Survey Vehicle, Hawkeye Processing Toolkit Software, Bump Integrator etc. can be used in further scope of the research. Also, the number of rural road stretches selected in Himachal Pradesh for collecting field data can be increased in further research work.

The structural evaluation data collected on the selected twelve rural road stretches in Shimla and Solan district of Himachal Pradesh are used in the present study to develop mathematical models to predict Benkelman beam characteristic deflection based on Soaked CBR, Un-soaked CBR, Average Annual Daily Traffic (AADT), Age of pavement from last overlay (in years) and K-value. The models have been developed using linear regression analysis with the help of sklearn library in PYTHON. The correlation matrix has been formed to check the correlation within the parameters. Soaked CBR and Unsoaked CBR are found to be highly correlated to each other and hence either of these may be neglected. In the present study, unsoaked CBR has been neglected in the modelling as soaked CBR being good representative of structural strength of pavement subgrade. The developed models have been compared based on conventional statistical parameters such as MAE, MSE, RMSE and R^2 values. It has been found that the model developed to predict pavement deflection using soaked CBR, AADT and age of pavement is found to be more accurate as R^2 value of 0.76 and RMSE value of 0.19 being good as compared to other model.

Modelling of characteristic deflection is very essential for the pavement maintenance management system and structural analysis of pavements. Prediction of characteristic deflection value using mathematical models can give easy estimates of overlay design without carrying out actual Benkelman beam survey in the field which leads to disruption of traffic on narrow rural roads of Himachal Pradesh and increase in cost of the project. The present study uses five structural parameters for predicting the pavement characteristic deflection. Future study may include some more structural parameters and more stretches may be selected of longer length in kilometres to further improve the present developed models.

7.2 Scope for future work

The scope for future work includes-

- More detailed analysis can be done by selecting more number of roads in the state of Himachal Pradesh
- The road category can be altered to National Highway, State Highway which are of major importance in Himachal Pradesh
- The data collection can be done by using modern equipments such as Bump Wheel Integrator, Falling Weight Deflectometer, Network Survey Vehicle etc.

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9. APPENDIX- I

QUESTIONNAIRE

Relative Importance of Parameters Corresponding to Pavement Performance & Maintenance

	Fundamental Scale
Intensity of Importance	**Definition**
1	Equal Importance
3	Somewhat more Important
5	Much More Important
7	Very Much More Important
9	Absolutely More Important
2,4,6,8	Intermediate Value when compromise is required between above

Please check the box with a tick (☑) for the relative importance between Group 1 & Group 2 parameters.

SAMPLE

For Example : If you think that road cracking is 5 times more important than road ravelling then put (☑) under 5 on left side towards cracking

Group 1 Parameter	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Group 2 Parameter**
Cracking					✓													Ravelling

For Example : If you think that road ravelling is 5 times more important than road cracking then put (☑) under 5 on right side towards ravelling

Group 1 Parameter	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Group 2 Parameter**
Cracking													✓					Ravelling

For Example : If you think that road cracking has equal importance to road ravelling then put (☑) under 1 in the centre

Group 1 Parameter	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Group 2 Parameter**
Cracking									✓									Ravelling

Start the Survey

Group 1 Parameter	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Group 2 Parameter**
Cracking																		Ravelling
Cracking																		Patching
Cracking																		Potholes
Cracking																		Rutting
Cracking																		Mean Texture Depth
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Ravelling																		Patching
Ravelling																		Potholes
Ravelling																		Rutting
Ravelling																		Mean Texture Depth
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Patching																		Potholes
Patching																		Rutting
Patching																		Mean Texture Depth
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Potholes																		Rutting
Potholes																		Mean Texture Depth
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Rutting																		Mean Texture Depth

APPENDIX-II

QUESTIONNAIRE

Relative Importance of Parameters Corresponding to Pavement Performance & Maintenance

	Fundamental Scale
Intensity of Importance	**Definition**
1	Equal Importance
3	Somewhat more Important
5	Much More Important
7	Very Much More Important
9	Absolutely More Important
2,4,6,8	Intermediate Value when compromise is required between above

PART-A

Please check the box with a tick (☑) for the relative importance between Group 1 & Group 2 parameters.

SAMPLE

For Example : If you think that road rutting is 5 times more important than road ravelling then put (☑) under 5 on left side towards cracking

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Rutting					✓													Ravelling

or Example : If you think that road rutting is 5 times more important than road cracking then put (☑) under 5 on right side towards ravellin

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Rutting													✓					Ravelling

For Example : If you think that road rutting has equal importance to road ravelling then put (☑) under 1 in the centre

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Rutting									✓									Ravelling

Start the Survey

Group 1 Parameter	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Group 2 Parameter
Longitudinal Cracking																		Ravelling
Longitudinal Cracking																		Patching
Longitudinal Cracking																		Potholes
Longitudinal Cracking																		Rutting
Longitudinal Cracking																		Mean Texture Depth
Longitudinal Cracking																		Transverse Cracking
Longitudinal Cracking																		Alligator Cracking
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Ravelling																		Patching
Ravelling																		Potholes
Ravelling																		Rutting
Ravelling																		Mean Texture Depth
Ravelling																		Transverse Cracking
Ravelling																		Alligator Cracking
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Patching																		Potholes
Patching																		Rutting
Patching																		Mean Texture Depth
Patching																		Transverse Cracking
Patching																		Alligator Cracking
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Potholes																		Rutting
Potholes																		Mean Texture Depth
Potholes																		Transverse Cracking
Potholes																		Alligator Cracking
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Rutting																		Mean Texture Depth
Rutting																		Transverse Cracking
Rutting																		Alligator Cracking
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Mean Texture Depth																		Transverse Cracking
Mean Texture Depth																		Alligator Cracking
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Transverse Cracking																		Alligator Cracking
	PART-B																	
	LEVEL-1																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Functional Condition																		Structural Condition
	LEVEL-2																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Pavement Distresses																		Pavement Roughness
Pavement Distresses																		Pavement Skid Resistance
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Pavement Roughness																		Pavement Skid Resistance
	LEVEL-3																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Pavement Modified Structural Number																		Pavement K-Value

11. LIST OF PUBLICATIONS

1. Aakash Gupta , Ashok Kumar Gupta, Ashish Kumar (2019). "Development of Maintenance Management System by Functional Evaluation for Rural Roads in Himachal Pradesh." *International Journal of Recent Technology and Engineering*, *8* (1), 1682-1690 **(SCOPUS Indexed/ Published)**
2. Aakash Gupta , Ashok Kumar Gupta, Ashish Kumar (2018). " Road Asset Management Using Pavement Performance Prediction Models." *Journal of Advanced Research in Dynamical and Control Systems, 10* (12), 300-310 **(SCOPUS Indexed/ Published)**
3. Aakash Gupta , Ashok Kumar Gupta, Ashish Kumar (2019). "A model for Pavement Characteristic Deflection for Rural Roads in Himachal Pradesh" Periodicals of Engineering and Natural Science **(SCOPUS Indexed/ Under Review after First Revision)**
4. Aakash Gupta , Ashok Kumar Gupta, Ashish Kumar (2019). "Development of Road Roughness Model using Analytical Hierarchy Process for Rural Road Network in Himachal Pradesh" International Journal of Pavement Research and Technology **(Springer/ Submitted)**
5. Aakash Gupta, Ashok Kumar Gupta, Ashish Kumar (2019). "Rural Road Maintenance Prioritization Index based on Functional and Structural Parameters for Rural Road Network in Himachal Pradesh" *Journal of Transportation Engineering Part-B Pavements* **(ASCE/Submitted)**